

## **CHAPTER IV**

### **MODEL INPUT DATA**

This chapter presents the details of the input data that are required for development of Paya Indah wetland model. The procedure of model development, calibration and validation, statistical evolution for the model performance, sensitivity analysis and the thereafter simulation of various management scenarios on the watershed are also provided.

#### **4.1 HYDRO-METEOROLOGICAL DATA**

##### **4.1.1 Rainfall**

Rainfall data were obtained from Malaysia Meteorological Department (MMD) and Drainage and Irrigation Department of Malaysia (DID). The rainfall distribution is highly variable in both time and space across the modelled catchment. Accumulated daily rainfall was accounted for four stations within or close to the catchment. The rainfall input was directly linked to each station and the controlled area for each station was determined by creating a Thiessen polygon using the terrace GIS tool. These stations include Bukit Cheeding, Sungai Manggis, Prang Besar, and Kuala Lumpur International Airport (KLIA) (Figure 4.1). The rainfall input for the model was spatially distributed according to weighted method in

which the total rainfall was calculated from the measured rainfall and the area weight factors (Table 4.1). The data were converted into the MIKE SHE timeseries format (Figure 4.2).

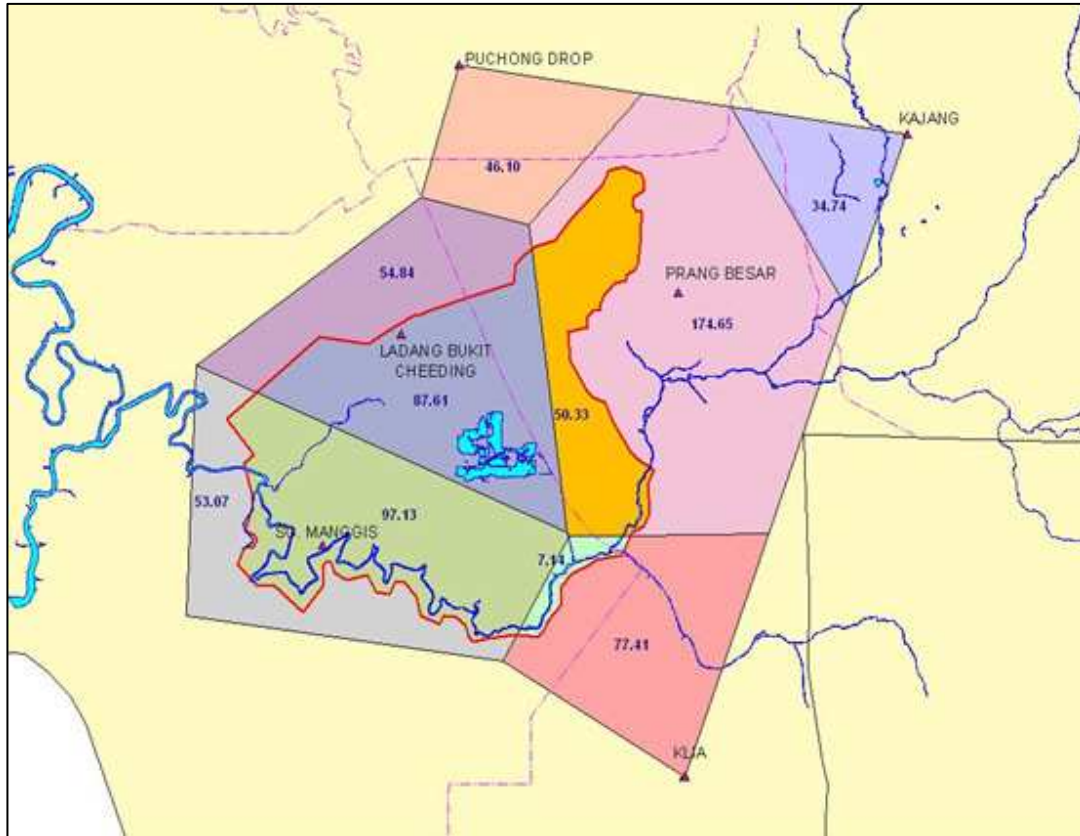
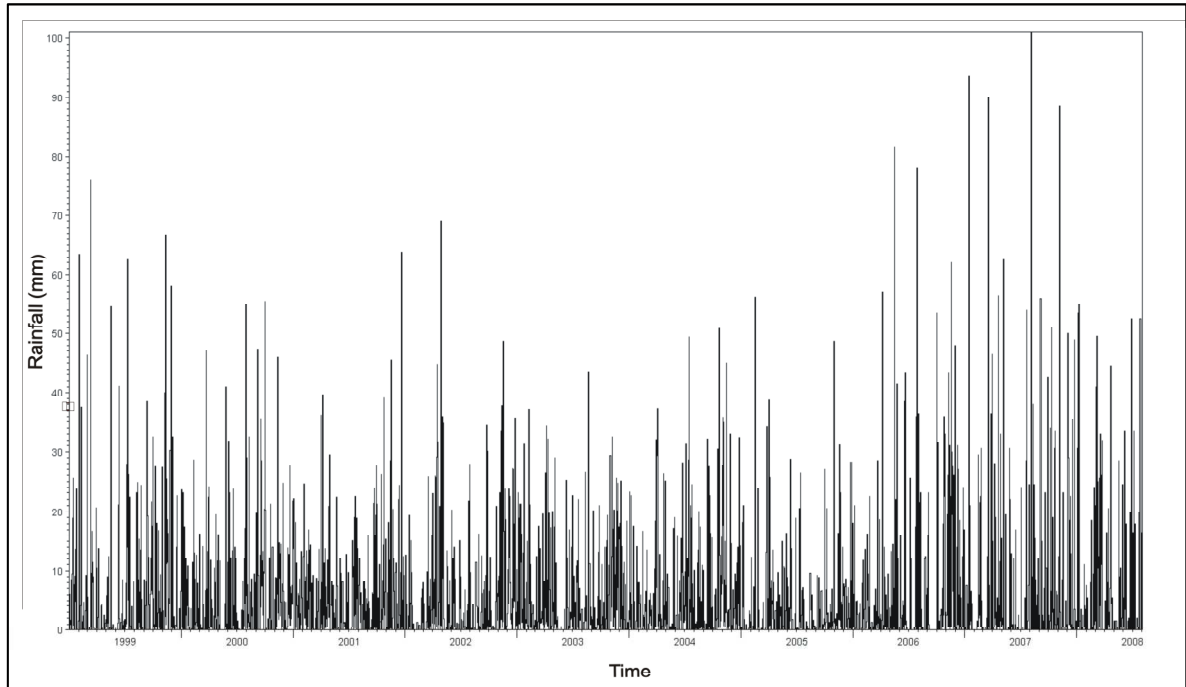


FIGURE 4.1  
Estimated Rainfall Fields for the Catchment using Thiessen-polygon Method

TABLE 4.1  
Rainfall Area Weighted Factors for the Paya Indah  
Wetland Catchment\*

Station	Weighted Factor (%100)
Sungai Manggis	40.10
Bukit Cheeding	36.17
Perang Besar	20.78
KLIA	2.95

\* Area 242.21 km<sup>2</sup>



**FIGURE 4.2**  
**Hyetograph of the Paya Indah Wetland Catchment**

Since the rainfall is the main water source to the Paya Indah wetland catchment and it is therefore essential to furnish the knowledge with a detailed description of local rainfall patterns. Thus, the rainfall depths were processed and converted into rainfall intensities ( $\text{Intensity} = \text{Depth}/\text{Duration}$ ), which are then presented in a form of intensity-duration-frequency (IDF) curves based on the fact that total rainfall depth of a storm at a point, for certain duration of rainfall and the average recurrence interval (ARI), are function of the local climate. All the data, calculation and curves IDF are presented in Appendix C; while monthly rainfall data are presented in Table D.1 (Appendix D)

### 4.1.2 Evapotranspiration

Potential evapotranspiration (Appendix E) was calculated using the Penman method (Penman, 1948) which requires daily minimum and maximum temperature, relative humidity, wind speed and percentage cloud cover. These data, together with daily rainfall, were obtained from the KLIA meteorological station. The model simulates the actual evapotranspiration rate. It is calculated at each time step as a percentage of the potential evapotranspiration rate. Measured rainfall time series must thus be specified as part of the model input (Figure 4.3). The data are primarily used to simulate soil or free water surface evaporation and plant transpiration. Consequently a crop vegetation specific potential evapotranspiration rate is needed.

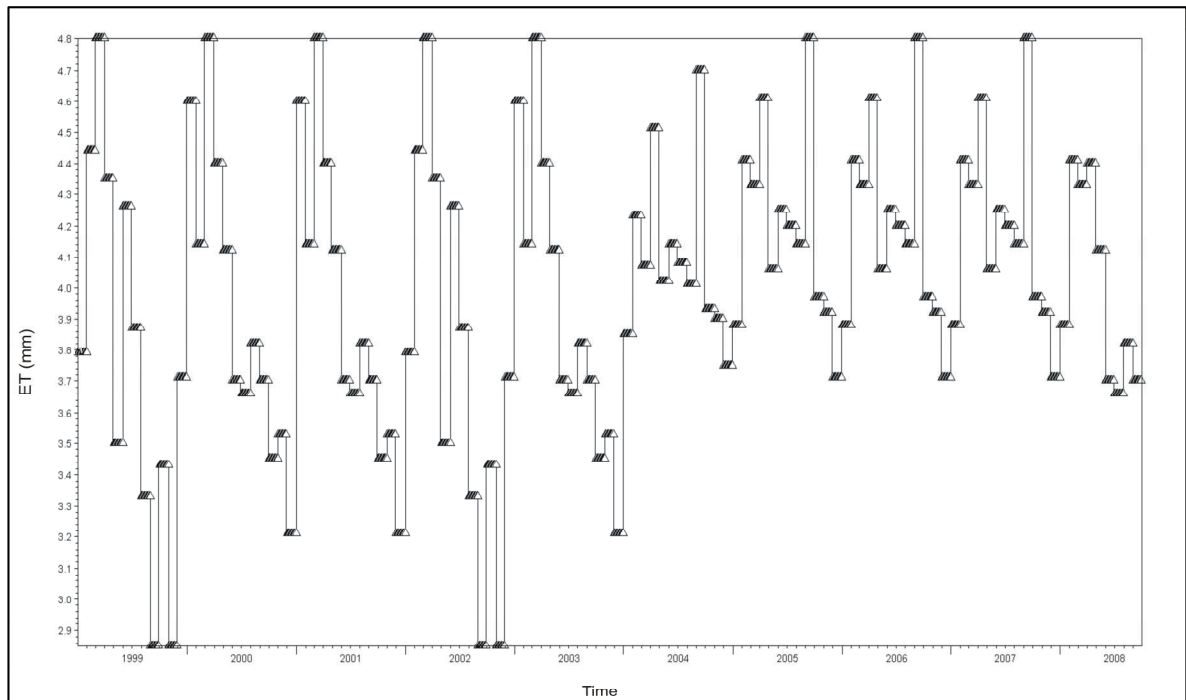


FIGURE 4.3  
Daily Evapotranspiration for the Paya Indah Wetland Catchment

## 4.2 LANDUSE AND VEGETATION

Leaf area index and root mass distribution are vegetation specific parameters. The distribution of vegetation parameters is based on the identification of the dominant characteristic vegetation/land use types in the basin. The land use impact is mainly caused by logging activities, especially at the area north to the Main Lake where the forest was removed and the land left barren. The fact that the land is left barren is the main cause of concern as this initiates the process of peat decay and subsidence. Land use maps are used to distribute vegetation specific parameters (Table 4.2). Land use maps based on aerial photos and field inventories exist for 1998 and 2006 as GIS polygon coverage (Figure 4.4).

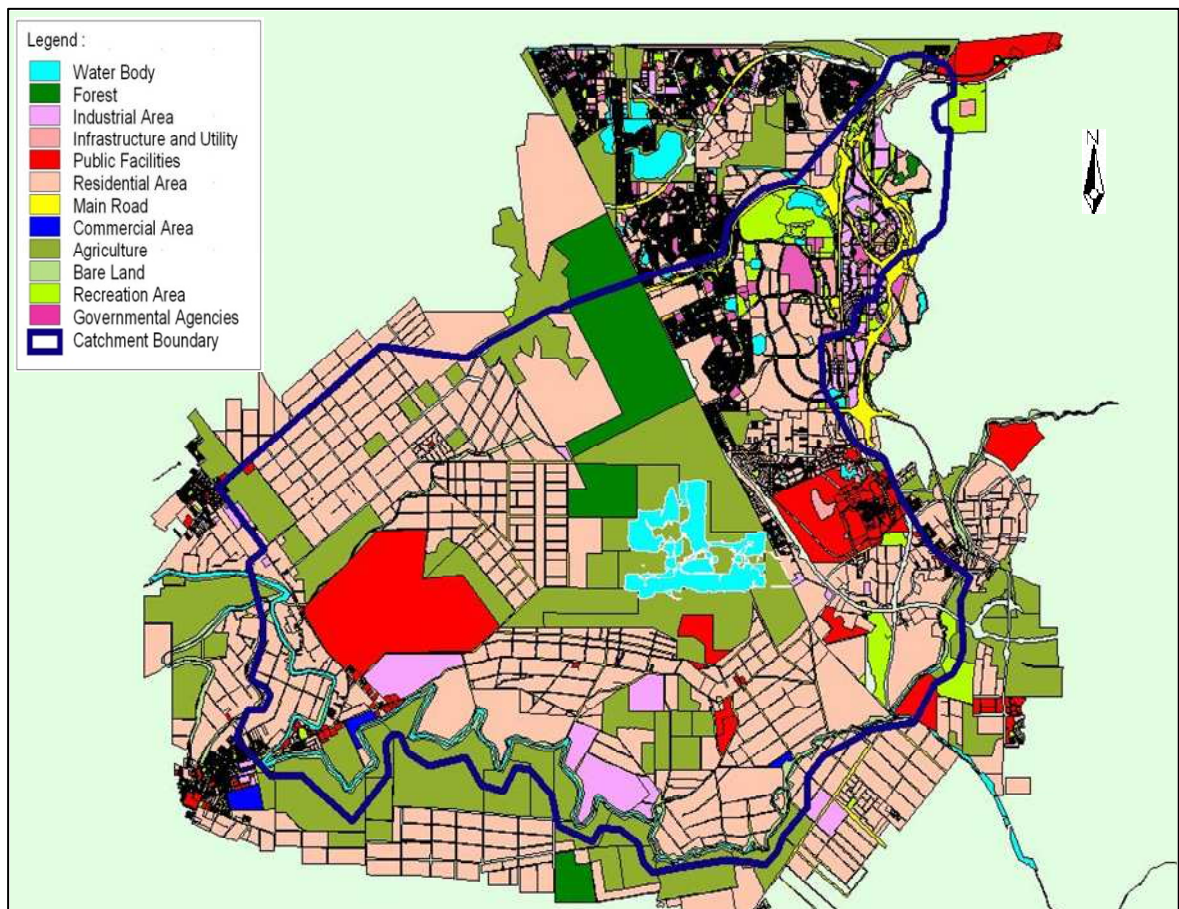


FIGURE 4.4  
Landuse Map of the Paya Indah Wetland Catchment

TABLE 4.2  
Properties of Vegetation within the Paya Indah Wetland Catchment

Vegetation Development	Township				Citrus			
	D.O.G <sup>1</sup>	LAI <sup>2</sup>	RD <sup>3</sup>	Kc <sup>4</sup>	D.O.G	LAI	RD	Kc
Planting	0	2	200	0.50	0	4.5	1250	1
Harvest	365	2	200	0.50	365	4.5	1250	1

Vegetation Development	Sugar Cane				Pasture			
	D.O.G	LAI	RD	Kc	D.O.G	LAI	RD	Kc
Planting	0.0	1.0	500	1	0	3	600	1
Early-season	60	2.0	1000	1	150	3	600	1
Mid-season	90	2.5	1500	1	240	4	600	1
Late-season	120	3.5	1500	1	330	4	600	1
1 <sup>st</sup> Harvest	150	4.5	1500	1	365	3	600	1
2 <sup>nd</sup> Harvest	210	5.5	1500	1				
3 <sup>rd</sup> harvest	365	6.0	1500	1				

Vegetation Development	Truck Crop				Grass			
	D.O.G	LAI	RD	Kc	D.O.G	LAI	RD	Kc
Planting	0	4.5	750	1	0	3	750	1
Harvest	365	4.5	750	1	365	3	750	1

Vegetation Development	Shrub				Marsh			
	D.O.G	LAI	RD	Kc	D.O.G	LAI	RD	Kc
Planting	0	3	750	1	0	2	750	1
Harvest	365	3	750	1	150	3	750	1
					365	3	750	1

Vegetation Development	Sparse Forest				Oil Palm			
	D.O.G	LAI	RD	Kc	D.O.G	LAI	RD	Kc
Planting	0	3	750	1	0	2.5	1	0.85
Harvest	365	3	750	1	365	2.5	1	0.90

<sup>1</sup>LAI: leaf area index (m<sup>2</sup> m<sup>-2</sup>);

<sup>2</sup>RD: rooting depth (mm);

<sup>3</sup>Kc: crop coefficient (-);

<sup>4</sup>D.O.G: days of growth

Oil Palm plantations now cover most of the former peat swamp. However, Northwest of Paya Indah Lakes within the Kuala Langat District, there are still some areas covered by natural peat swamp forest. For each land use type, the model requires the leaf area index (LAI), rooting depth (RD) and crop coefficient (Kc) to be entered into the vegetation property file. Table 4.2 shows the values assigned for the different crops and trees cultivated within the catchment based on the landuse map of Kuala Langat District for the year 2006 (Figure 4.4).

### **4.3 SURFACE TOPOGRAPHY**

Ground surface elevation is used by the overland flow model and as a reference level for the unsaturated and saturated zone models.

Surface topographic information is available via two data sources:

- digitized topographic maps (20 m contour lines)
- detailed topographic surveys in Cyberjaya

The 20 meter contours are, however, of limited use in the swamp areas which are essentially without any topographic relief. For the peat areas the topographic elevations have been estimated from a few spot elevations at borehole locations carried as part of the JICA study (Minerals and Geoscience Department of Malaysia, 2002). Finally, spot elevations are available along the Langat River and areas in between the Lakes (Jurukur Permata Malaysia, 2003). The available topographic data were sufficient to establish a hydrological model. However, there were obvious data lacks in the peat swamp areas and although the area is essentially flat there may easily be uncertainties approximately in the order of 0.5 m. At most locations the model was however able to predict the relative impacts on the ground-



water level, this was a key requirement for the model. The topographic data are illustrated in Figures 4.5 and 4.6. The resulting interpolated land surface is shown in Figure 4.7.

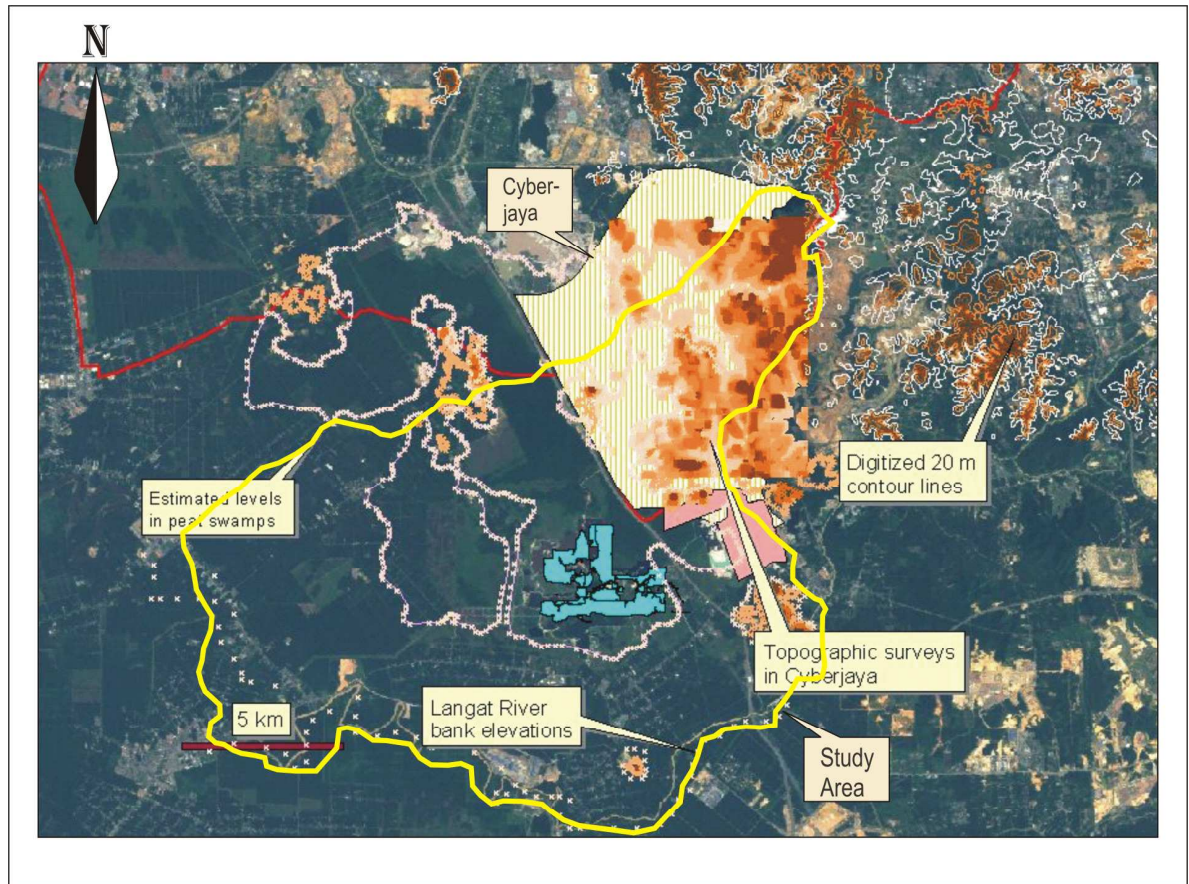


FIGURE 4.5  
Topography Data



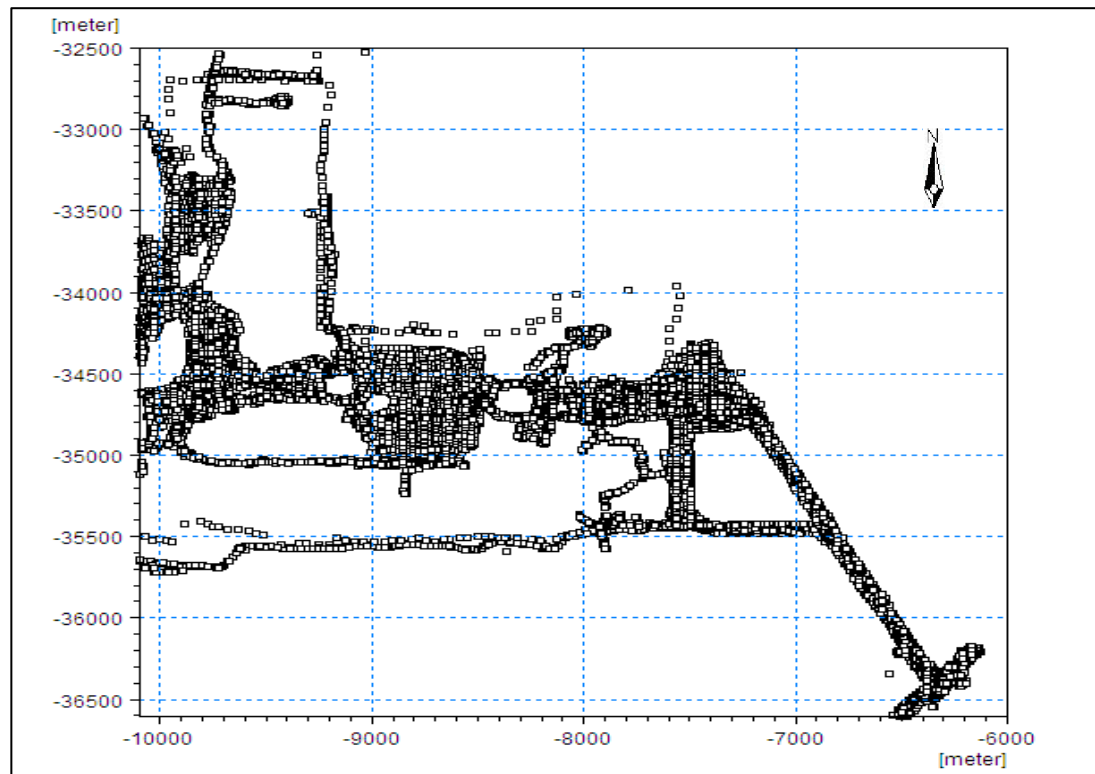


FIGURE 4.6  
Layout of Paya Indah Lakes System showing the Locations of the Spot Level Data

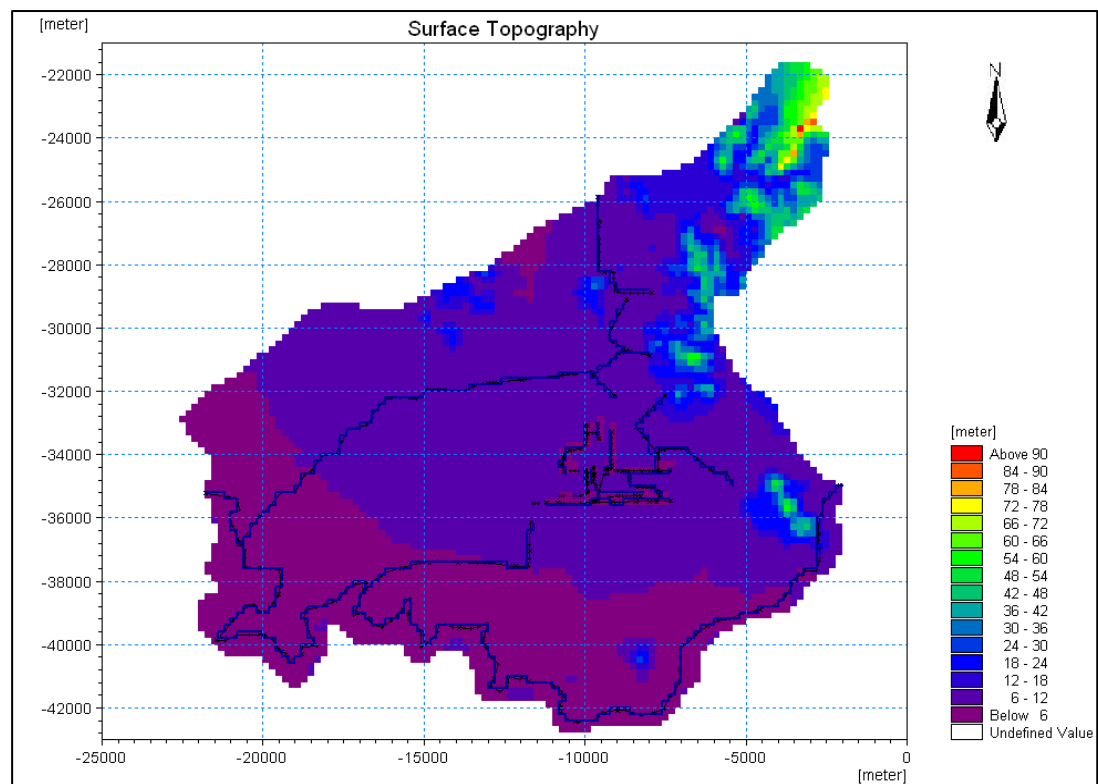


FIGURE 4.7  
Topographic Model of the Paya Indah Wetland Catchment

#### 4.4 OVERLAND FLOW AND RIVER NETWORK

Overland sheet flow occurs when the water depth on the ground surface is larger than zero. Besides surface topographic elevations, detention storage and roughness coefficient (Manning's  $M$ ), the required input data for the MIKE11 model consists of branch network, cross-sections, control structure geometry and operation schedules. However, although there were some operations at the weir at Lotus Outlet (Figure 4.8) but according to the Paya Indah administrative officers there are no measurements have been recorded

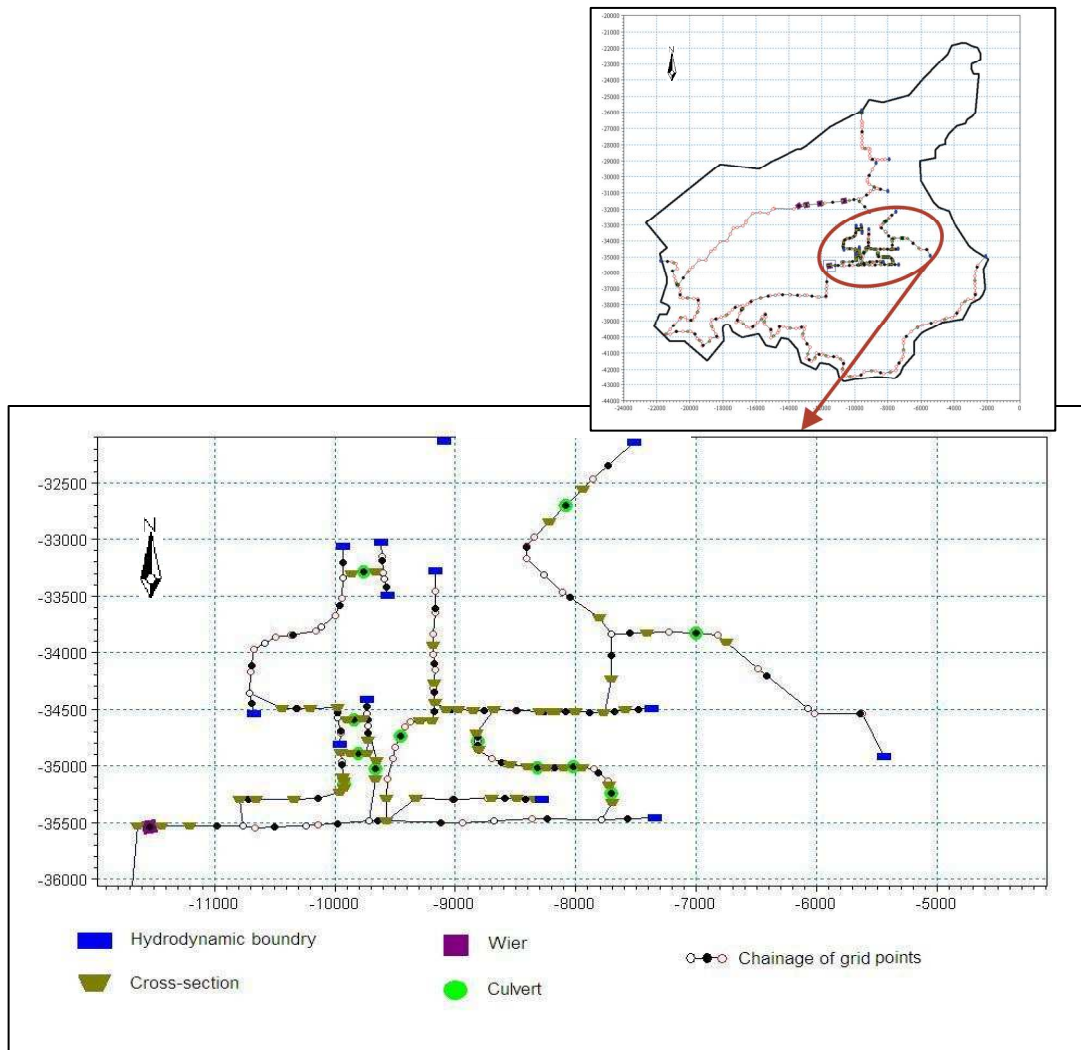


FIGURE 4.8  
Zooming-in for Set-up of Channel Flow Network the Location of Hydrodynamic Boundaries, Cross-sections, Culvert and the Lotus Lake Outlet Controlled Gate

#### 4.4.1 Overland flow and detention storage

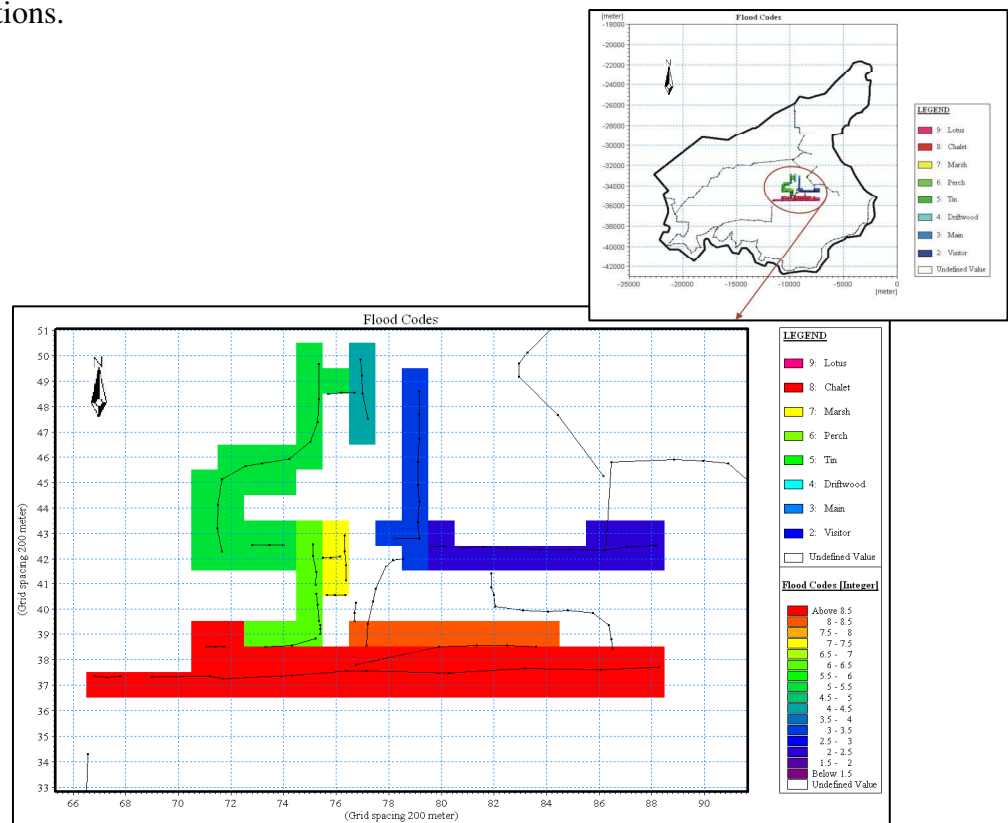
The model area is dominated by peat swamp relatively flat with little topographical relief. Thus the overland flow is not considered of great importance in a peat swamp as the undulating ground surface restricts the surface flow. However, for the other types of soils the over land flow direction and velocity were determined by the ground surface slope and roughness coefficient. The surface topography was interpolated into the 200x200 m mesh using an inverse-distance weighted interpolation routine. A 20-m map has been created as input for the model by interpolation. Detention storage of 0.005 m, was assumed to represent micro-variations on the ground surface that could not be described by the 200-m model grid resolution

The topographic elevation varies from 90 m.a.s.l. in the northwest corner of the Modeled area to about 1 m.a.s.l at the bottom boundary (Figure 4.7). The land surface elevation in North Kuala Langat peat swamp forest is about 7.5 m gradually declining towards the Langat riverbank. The measured topographic elevation of the areas in between the lakes is in the order of 8.0 to 9.0 m.

Overland flow only occurs during storm events. More important is the depression storage i.e. low lying areas receiving overland flow or drainage flow. The surface detention volume is described by the topography. Ponding water accumulates as depression storage until the water level exceeds topographical thresholds separating the depression from surrounding areas. Pondered water may also infiltrate limited either by the infiltration capacity of the underlying unsaturated zone, or when the soil is entirely saturated, the leakage coefficient between the overland component and the saturated zone.

#### 4.4.2 Flooded areas

At high water levels following rainfall events the river inundates the floodplain. When the river water levels recedes water accumulated on the floodplain drains back to the river. Dynamic floodplain simulation of the river/floodplain interaction is important in order to describe flow attenuation and surface water storage. With the exception of the narrow tongue at the Northeastern corner of the catchment, the ground surface is generally flat with a number of flooded areas (lakes) and flood plains or depressions mainly at the Kuala Langat swamp forest. The Paya Indah lakes were assigned as flooded area by give a code for each lake (Figure 4.9 and), where as depression and flood plain data has been derived from the topographical model (Figure 4.7) by comparing river bank elevations to the surrounding surface elevations.



**FIGURE 4.9**  
Flooded Areas within of the Paya Indah Wetland Catchment: Lakes names and their representing code number

#### 4.4.3 Cross sections and bathymetry data

Being physically based, the hydraulic model component requires geometric (cross-sectional shape) data for the primary drainage channels. Channel cross-sections are available for the major drainage channels in the area and for Langat River along the southern model boundary. Diameter and invert elevations on culverts that divert water across the NSECL to Paya Indah are available. Lake Bathymetry data are surveyed only for nine lakes including Visitor, Main, Tin, Perch, Marsh, Lotus, Crocodile, Hippo and Chalet Lakes. Surface-elevation relations for the remaining lakes were estimated based on GIS data assuming that the lake surface area remains constant or only varies slightly, within the maximum and minimum lake water stages (Figure 4.10). Such assumption is reasonable because the bank slopes in the higher parts of the lake (the active storage) are very steep.

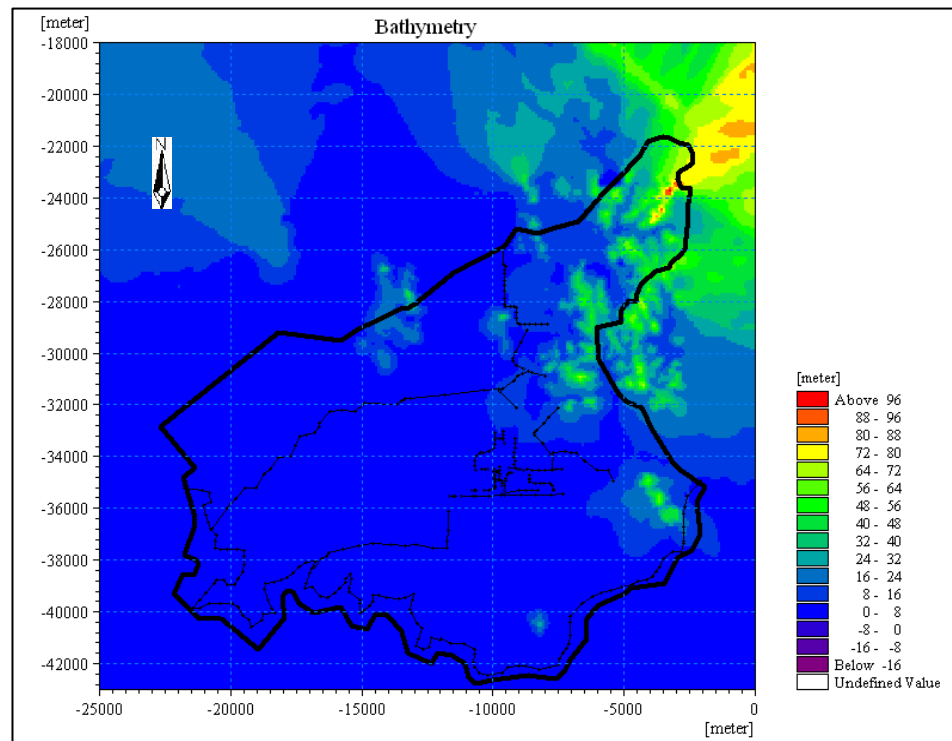


FIGURE 4.10  
Bathymetry model

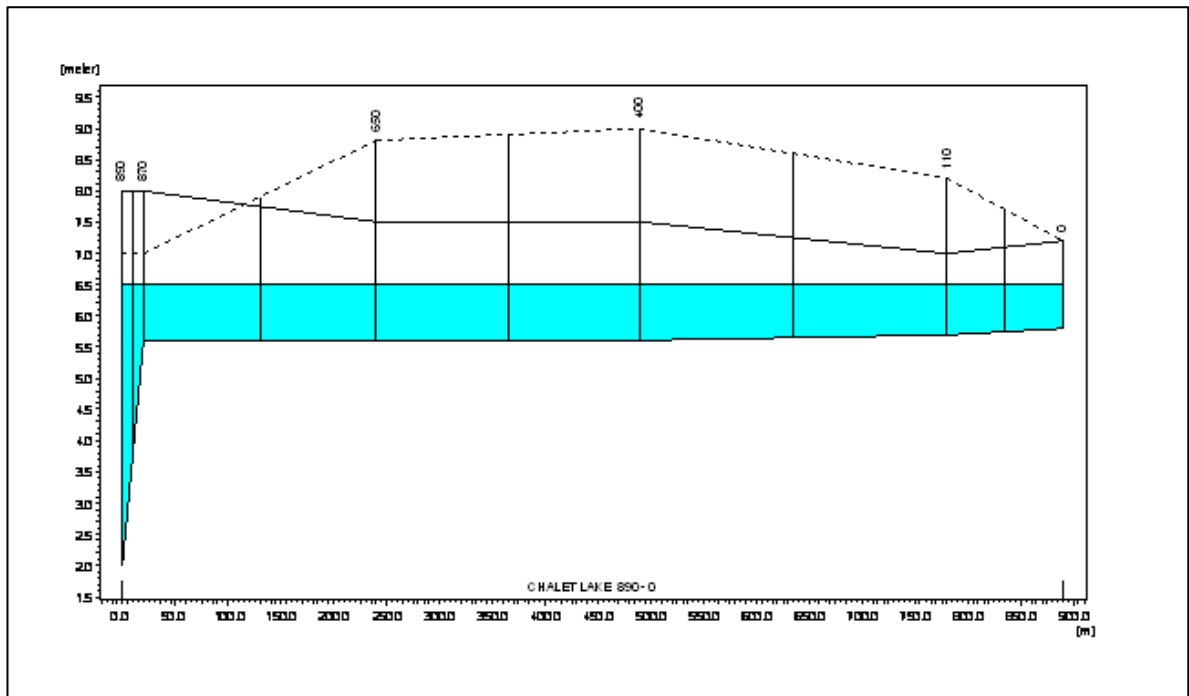


FIGURE 4.12  
Longitudinal Profile for Chalet Lake

## 4.5 UNSATURATED ZONE

Topsoil properties are important for the simulation of the infiltration and evapotranspiration processes that takes place in root zone.

### 4.5.1 Types of soils

Peat represents the key-interest of this study since it is the predominant type of soil within the catchment. Other soil types include Mined Land soil association (Sandy clay), Selangor-Kangkung series (alluvial sediments), Perang series (clay loam), Serdang-Bungor-Munchong series (clay loam) and some sedimentary rock outcrops (Figure 4.13; Appendix G).



A number of channels and culverts interconnect the lakes within the catchment. The precise geometry of Langat River Data have been collected from DID, while as for lakes and the interconnect channels, the geometry (cross-section and structures geometry) has been made through field survey. The invert elevations have been estimated by studying the water level variations in the various lakes. For some of the new development, for instance new drainage channels in Cyberjaya, the precise design data are incorporated in the hydraulic model. Cross-sections details for all the branches that comprise the surface water (River) model were summed up in Table F.1 in Appendix F. However, for instance, Figures 4.11 and 4.12 illustrate longitudinal profile views for some parts of the Paya Indah wetland channel network.

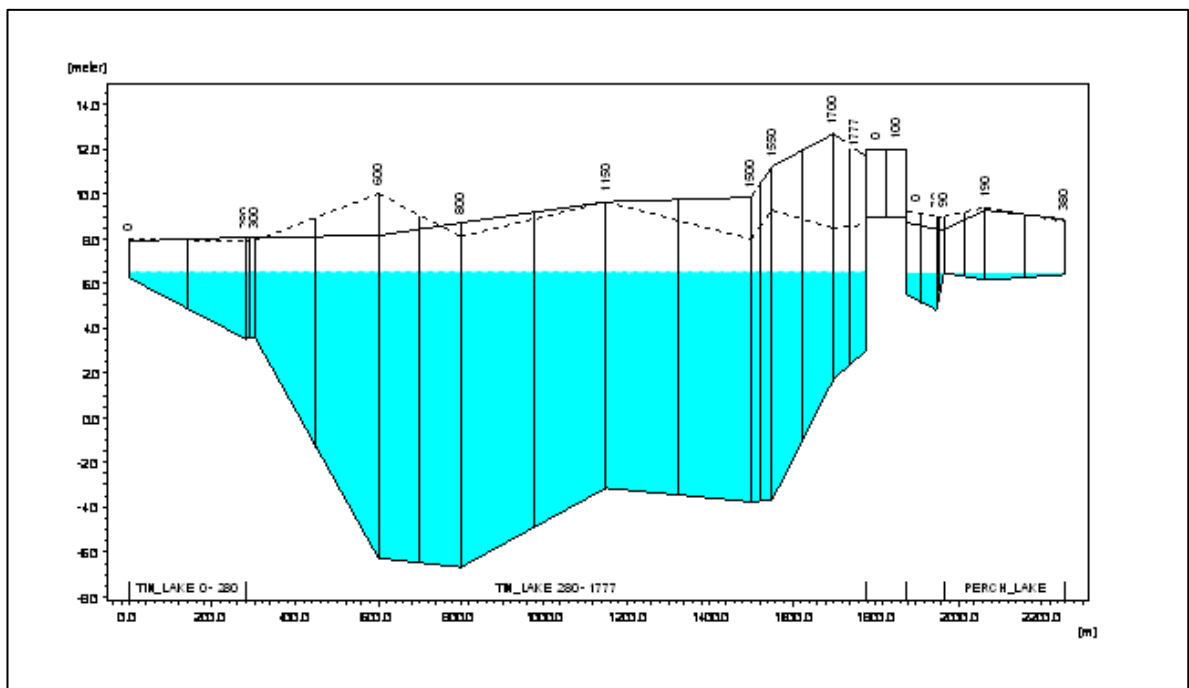


FIGURE 4.11  
Longitudinal Profile for Tin Lake, Tin-Perch-Connect and Perch Lake

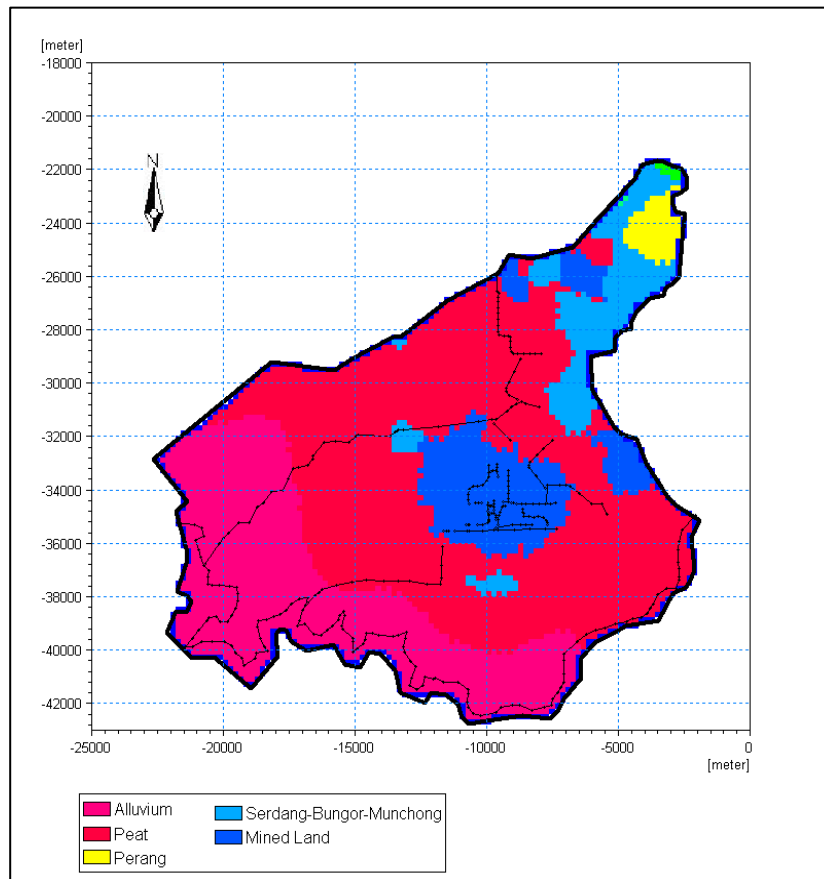


FIGURE 4.13  
Soil Map of the Paya Indah Wetland Catchment

#### 4.5.2 Soil water

Water in the soil resides within soil pores in close association with soil particles. The largest pores transport water to fill smaller pores. After saturation due to rainfall and/or irrigation, the large pores drain due to gravity and water is held by the attraction of small pores and soil particles. Soils with small pores (clayey soils) hold more water per unit volume than soils with large pores (sandy soils). After complete wetting and time is allowed for soil to dewater the large pores, a typical soil will have about 50% of the pore space as water and 50% as air. Figure 4.14 shows a schematic description for the volume/weight relationships of any certain bulk of soil.

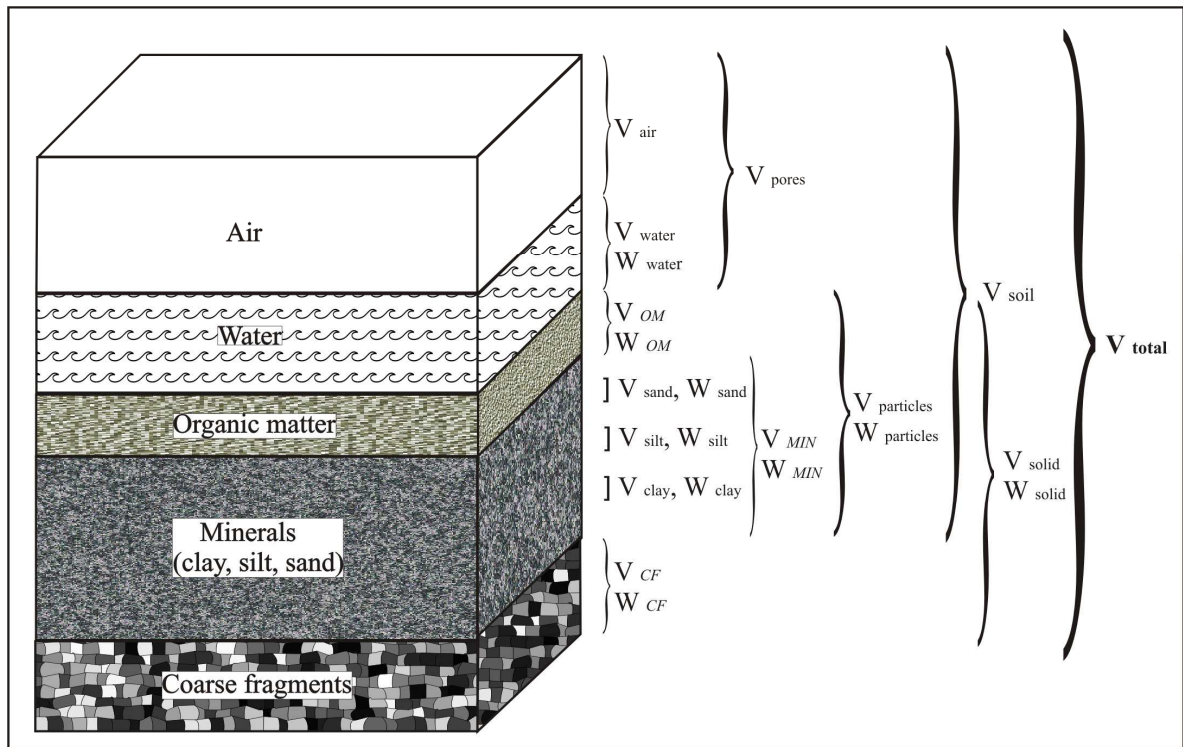


FIGURE 4.14

Overview of Soil Volume/Weight Relationship: “V” and “W” represent volume and weight, respectively; “soil” refers to the fine earth fraction (any combination of sand, silt and clay minerals mixed with soil organic matter and pores), but excludes coarse fragments (CF); “soil particles” refer to fine earth minerals and organic matter. Solid refers to fine earth +CF. Total volume refers to fine earth, CF and pores. (Modified after Balland et al., 2008)

#### (a) Theory

It is a basic assumption that water flow in the unsaturated zone can take place as Darcy flow within the soil matrix or as gravity flow in distinct macropores (macropore flow) or as matrix flow regime which is described by Richards’s equation. Thus, the water movement in unsaturated soil is governed equation derived by is a combination of Darcy’s law and the principle of mass conservation (Richard, 1931). The pressure head form of the equation for the one-dimensional vertical flow is:

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z} \left[ K(h) \left( \frac{\partial h}{\partial z} + 1 \right) \right] - S(h) \quad (4.1)$$

where,

$C(h)$  is the differential water capacity ( $\partial\theta/\partial h$ ) ( $L^{-1}$ )

$\theta$  is the volumetric water content ( $L^3/L^3$ )

$h$  is the soil water pressure head (matrix) (L)

$t$  is the time (T)

$z$  is the vertical coordinate (L)

$K$  is the isotropic hydraulic conductivity (L/T)

$S$  is the sink term which represents the root water extraction ( $L^3/L^3/T$ )

Richards's equation remains the most general method to compute hydrological processes particularly in coupled surface water and groundwater interaction models. These processes include soil moistures and hydrological fluxes such as infiltration, runoff, ET and groundwater recharge. Soil layering, shallow groundwater table and the effects of soil moisture on infiltration, are all easily incorporated into the Richards's equation model solution (Downer and Ogden, 2004).

A solution to Richard's equation requires knowledge of a relation between  $\theta$  and  $h$ , i.e. a soil water characteristic or retention curve, and knowledge of relation between  $K$  and  $h$  or  $\theta$ , i.e. the hydraulic conductivity function. Van Genuchten's retention function (Van Genuchten, 1980) is the most widely used because it is continuous over the entire range of pressure head which leads to stable numerical solutions for Equation 4.1. Van Genuchten

also derived the  $K(\theta)$  relationship using the capillary-based unsaturated hydraulic conductivity prediction model developed by Mualem (1976). The soil hydraulic functions are:

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r \text{ for } \theta_s \geq \theta \geq \theta_r}{(1 + |\alpha h|^n)^m} \quad (4.2)$$

$$K(h) = K_s \frac{\left[ (1 + |\alpha h|^n)^m - |\alpha h|^{n-1} \right]^2}{(1 + |\alpha h|^n)^{m(1+2)}} \quad (4.3)$$

where

$\theta_s$  and  $\theta_r$  are the saturated and the residual water content, respectively ( $\text{L}^3 \text{L}^{-3}$ )

$\alpha$  is approximately the inverse of bubbling pressure head ( $\text{L}^{-1}$ )

$n$  is the pore size distribution index (—)

$m$  is  $1 - (1/n)$  (—)

$K_s$  is the saturated hydraulic conductivity ( $\text{L T}^{-1}$ )

$L$  is a parameter (—) usually chosen to be 0.5

### 4.5.3 Soil sampling and insitu measurements

MIKE SHE offers a range of built-in infiltration models. For the Paya Indah model the simplest approach was applied which basically establishes a mass balance for the root zone and calculates average moisture content for the entire root zone. If a sufficient amount of water is available within the root zone or in the capillary fringe the simulated actual evapotranspiration will equal the potential rate. In water shortage situation the potential rate will

be reduced as a function of the available soil moisture in the root zone. The model has the benefits of being simple to use and fast to run but still be based on physical soil properties. For the Paya Indah model soil physical properties was distributed spatially using the soil map presented in Figure 4.13. The lower boundary condition for the unsaturated zone model will be the simulated groundwater head. Hence, the depth of the unsaturated zone changes dynamically depending on the climatic and hydrological conditions. For the soil hydraulic properties, a total of ten random locations were chosen for each soil type (Figure 4.15) for insitu measurements and disturbed soil sampling for the other laboratory tests.

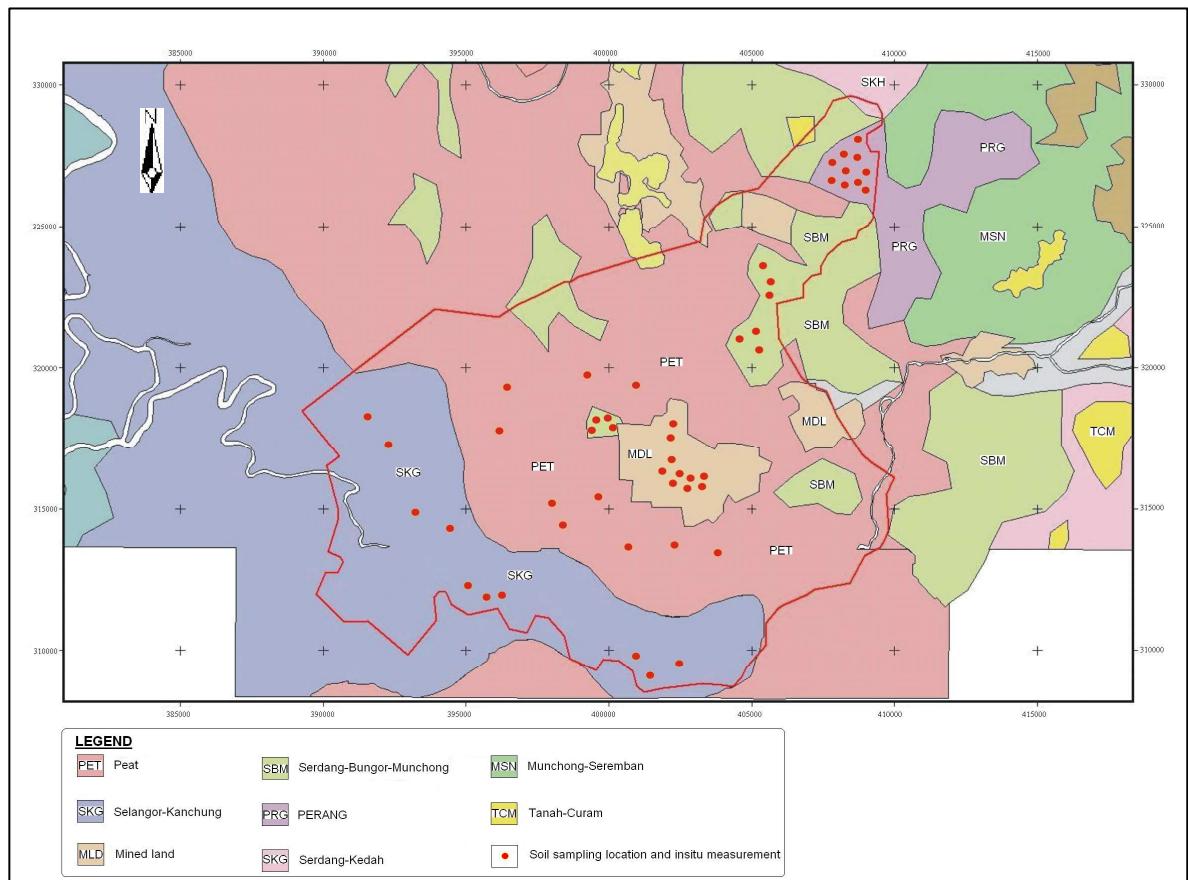


FIGURE 4.15  
Locations of Soil Sampling and Insitu Measurements



The locations were chosen based on the accessibility especially for the peat where the peat swampy forest occupied parts of the northern and northwestern areas of the catchment. Samples (1 kg each) were collected from vadose zone at depth of 20 cm from ground surface using hand tools (Shovel, Trowel and Auger), and then packed in plastic bags before sending to laboratory. The soil samples were air-dried at room temperature for two weeks. Using a ceramic pestle and mortar, samples were gently ground and sieved through a No. 2 sieve. Soil samples with particle sizes of  $< 2$  mm were preserved in sealed plastic bags for laboratory testing (Bahaa-eldin et al., 2003; US EPA, 2000).

Direct heating is the standard method for soil water content determination ( $\theta_v$ ). In this context, two separate sets (ten each) of samples of about 100g each were taken from each soil type in order to determine the soil available water capacity (AWC). These sets aimed at measuring the soil water content at field capacity ( $\theta_{FC}$ ) and permanent wilting point ( $\theta_{WP}$ ). The sampling process took place in the periods of 18 March – 12 April 2007 and 16 December 2007 – 22 January 2008.

Field capacity is frequently near the soil water content at 0.1 bar of tension for coarser-textured soils (sands, loamy sands) and 0.33 bar of tension for finer-textured soils (loams, silt loams). One bar is equal to one atmosphere of pressure or 14.7 psi. Permanent wilting point is usually taken as the soil water content at 15 bars of tension. Permanent wilting point can vary widely for different crops. There is little error in the total available water when a value of 15 bars of tension is used because the amount of water involved at high soil water tension levels is quite small (Ley et al., 1994).

Water content at field capacity is a theoretical value which should be attained by the soil after a period of free drainage (Bernier et al., 2002). Accordingly,  $\theta_{FC}$  was measured after three days of significant rain events. Immediately after sampling, samples were placed into leak-proof, seamless, pre-weighed and identified aluminum containers. Furthermore the containers were sealed by tape to avoid evaporation of the soil moisture.

#### **4.5.4 Soil characterization**

##### **(a) Specific gravity**

Soil particle specific gravity ( $\rho_d$ ) is the ratio of the mass of a unit volume of soil solids to the same volume of gas-free distilled water at a temperature of 20° C (ASTM, 2000). It was determined according to ASTM (2000) standard. The bottle used for measurements was cleaned and dried and then its mass was determined and recorded. Then it was filled with distilled water, having a temperature of  $20 \pm 5^\circ$  C. The mass of the bottle and water ( $W_0$ ) was determined in grams. An amount of 10 g of oven-dried at 105° C representative soil sample ( $W_a$ ) was placed into the bottle at room temperature. Then the distilled water was added up to the half-full of the bottle. The entrapped air was removed by gently boiling the contents for 15 minutes while occasionally rolling the bottle to assist in removing the air. The bottle was filled up with distilled water and left standing overnight. More distilled water was added to compensate the loss of water. The mass of the bottle and contents ( $W_b$ ) was determined in gram.

The specific gravity of soil ( $G_s$ ) was calculated as follows:

$$\rho_d = \frac{W_a}{(W_a + W_0 + W_b)} \quad (4.4)$$

where

$W_a$  is mass in gram of sample of oven dried soil

$W_0$  is mass in gram of stopper bottle and distilled water

$W_b$  is mass in gram of stopper bottle filled with water and soil

**(b) Soil water content at saturation condition: Porosity**

The porosity ( $\Phi$ ) of soil samples was calculated from the values of specific gravity using an equation adopted from McCauley et al. (2002) in which:

$$\Phi = 1 - \left( \frac{\rho_b}{\rho_d} \right) \quad (4.5)$$

where,

$\Phi$  is Porosity

$\rho_b$  is bulk density of sample, which is dry weight following oven drying divided by the natural volume of the same sample (Birkeland, 1984).

$\rho_d$  is particle density which is particle specific gravity of the sample

**(c) Available water capacity of soil**

Available water capacity (AWC) is the amount of water content available to plants from the time the soil stops draining water to the time the soil becomes too dry to prevent permanent wilting. MIKE SHE calculates total available soil water for plant growth for each soil type as the difference between the amounts of water retained at field capacity ( $\theta_{FC}$ ) minus that retained at the wilting point ( $\theta_{WP}$ ).

Soil water content was measured using a gravimetric method (Black, 1965) in which, the samples and containers were weighed before and after oven drying. Samples together with the lid-off containers were left for 24 hours inside an electrically heated oven at 105°C until the mass stabilizes at a constant value. Then samples were taken from the oven and placed in a desiccator contained an active desiccant (magnesium perchlorate) until it become cool. Thus the water content in dry weight basis ( $\theta_d$ ) was calculated using the following formula:

$$\theta_d = \frac{(\text{weight of wet soil} + \text{tare}) - (\text{weight of dry soil} + \text{tare})}{(\text{weight of dry soil} + \text{tare}) - (\text{tare})} = \frac{\text{weight of water}}{\text{weight of dry soil}} \quad (4.6)$$

Then, the volumetric water content ( $\theta_v$ ) at each soil layer was calculated by multiplying the mass water  $\theta_d$  (g water per g soil) by the bulk density ( $\text{g/cm}^3$ ) using the following formula:

$$\theta_v = \frac{\text{weight of water}}{\text{weight of dry soil}} \times \text{soil bulk density} \quad (4.7)$$

#### (d) Infiltration test

The double-ring infiltrometer test is a well recognized and documented technique for directly measuring soil infiltration rates (Gregory et al., 2005).

The infiltration rate of the soil was measured by using double ring metallic infiltrometer with 60 cm outer diameter and 30 cm inner diameter (Figure 4.16) as described by Bouwer (1986) and by ASTM (2003). There are two operational techniques used with the double-ring infiltrometer for measuring the flow of water into the ground including constant head and falling head tests. In the constant head test, the water level in the inner ring is maintained at a fixed level and the volume of water used to maintain this level is measured. Where as in the falling head test which was used for this study, the time that the water level takes to decrease in the inner ring is measured. However in both constant and falling head tests, the water level in the outer ring is maintained at a constant level to prevent leakage between rings and to force vertical infiltration from the inner ring.

The rings were carefully inserted to a depth of 15 cm, in order to avoid disturbance of the soil. Both rings were filled with water to the same height. The outer ring acts as a guard, ensuring that water in the inner ring moves only vertically down the profile, and does not seep sideways. The water level in the inner ring was recorded every 2 to 10 minutes during the first hour as the infiltration rate usually is higher, and then decreases as time passes depending on soil type. The rings were refilled if the water dropped to half the original level. Infiltration rates per time interval were calculated from the drop in water. These were converted to measurements in  $\text{mm h}^{-1}$ . This rate normally depends on the following factors:

1. moisture status of the soil
2. soil texture
3. soil structure
4. vegetation cover

As the soil becomes saturated the rate will depend on factors 2 - 4 only as these remain constant.

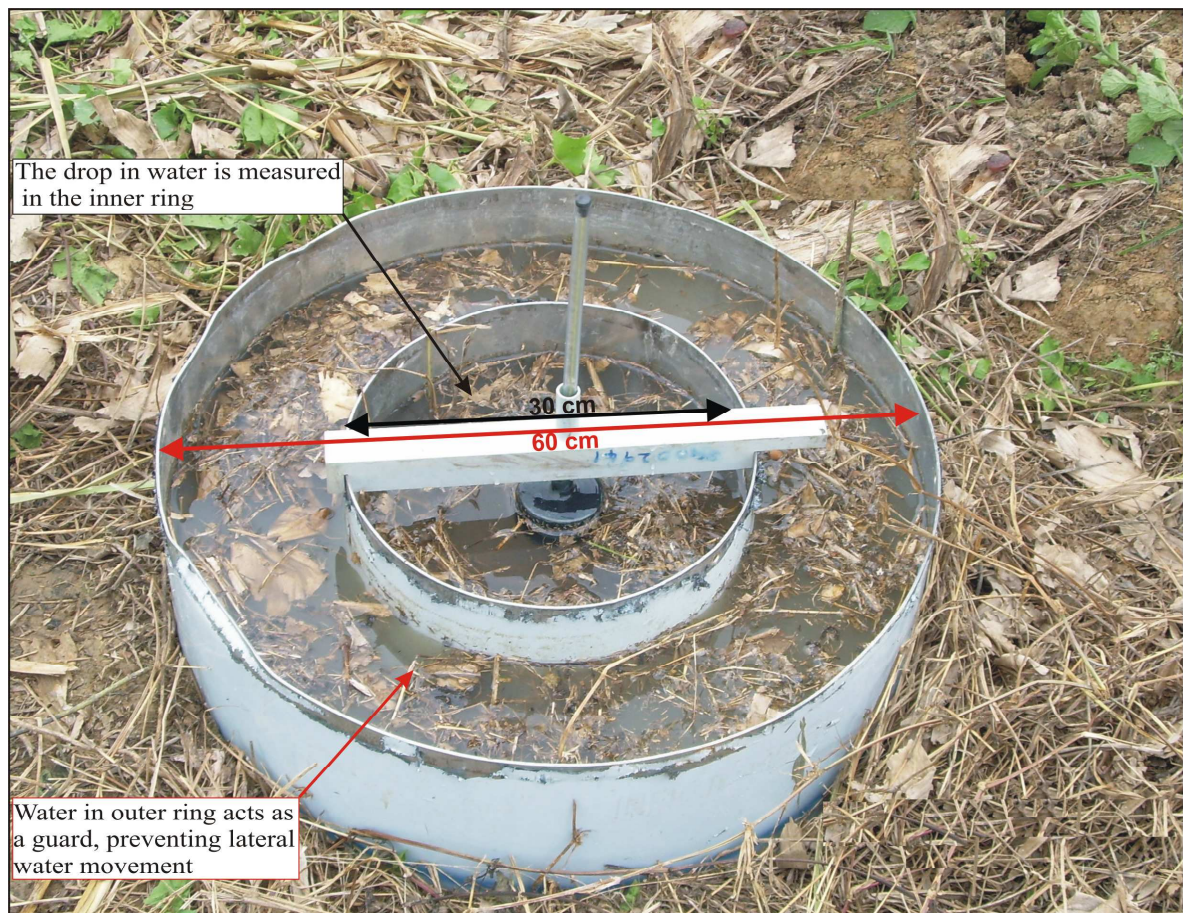


FIGURE 4.16  
Infiltration Test for the Selangor-Kanchung Series.  
Location: Kg Sg Manggis (Mangostine River Village)



#### 4.5.5 Presentation of soil tests results

The presented data represents average value of ten replicate measurements. Table 4.3 and Appendix H have summed up all the required hydraulic properties input data for all the soil types that were used to model the flow interaction in UZ for the Paya Indah wetland model.

TABLE 4.3  
Soil Hydraulic Properties Input Data used for the Model<sup>1</sup>

Soil Types <sup>2</sup>	$\rho_b$ (g/cm <sup>3</sup> )	$\rho_p$ (g/cm <sup>3</sup> )	$\Phi$	$\theta_{FC}$	$\theta_{WP}$	Infiltration (m/s)
PEAT	1.23-1.35	2.37	0.73**	0.68**	0.28	6.43E-05**
MDL	1.64-1.69	2.42	0.30	0.13	0.17	4.42E-08
SBM	1.46-1.48	2.44	0.37	0.29	0.22	4.53E-07
SKG	1.44-1.47	2.40	0.34	0.26	0.23	3.95E-07
PRG	1.42-1.45	2.42	0.41	0.30	0.17	6.63E-07

<sup>1</sup> n = 10;      \*\*  $P \leq 0.01$ ;    \*  $P \leq 0.05$ ;     $\rho_b$ : bulk density;     $\rho_p$ : particle density;  
 $\Phi$ : porosity (saturated water content  $\theta_s$ );     $\theta_{FC}$ : soil water content at field capacity;  
 $\theta_{WP}$ : soil water content at wilting point

<sup>2</sup>MDL: Mined Land soil association; SBM: Serdang-Bungor-Munchong series;  
 SKG: Selangor-Kanchung series;    PRG: Perang series;

The results show that peat which is dominated over the other soil types possesses the highest average infiltration rate (6.43E-05 m/s) where as the lowest value of 4.42E-08 m/s was measured in MDL. For each site the mean constant infiltration rate was determined using infiltration measurements from 60-120 minutes. Statistically the rate of infiltration of peat soil differed very significant ( $P \leq 0.01$ ) among the other four soil types within the catchment (Table 4.3). This result indicates that groundwater recharge from overland flow at areas dominated by MDL in particular area of the Paya Indah lakes system is the lowest com-

pared to the other parts within the catchment area. This result also supported by a very low average value of  $\Phi$  for MDL (0.30) which is equivalent to water content at saturation condition. While as peat is characterized by the highest porosity ( $\Phi$ ) average value of 0.73 which differs very significant at  $P \leq 0.01$  (Table 4.3). The soil water content at field capacity ( $\theta_{FC}$ ) differed greatly at  $P \leq 0.01$ . The highest mean value of  $\theta_{FC}$  (0.68) was measured for the peat; whereas MDL, SBM and PRG characterized by moderate to low soil moisture content ranges between 0.13 and 0.30.

The unsaturated zone extends from the ground surface to the groundwater table. The depth varies throughout the year with groundwater fluctuations simulated. During wet periods of the year, the unsaturated zone may occasionally disappear in depression areas where the water table rises above ground, e.g. the Kuala Langat swamp forest and the peat swamp areas to the south of the Paya Indah lakes system. Unsaturated zone flow is computed using a simple mass-balance evapotranspiration and recharge calculation method. The MIKE SHE computes recharge, actual evapotranspiration and average water content in the root zone. This simple approach is justified if the unsaturated zone is shallow and relatively wet. The spatial distribution of the soil types is based on the soil map shown in Figure 4.13. Each soil type is attached to a set of soil physical properties including volumetric moisture content at saturation, field capacity and wilting point, respectively (Table 4.3). These parameters are important both for the groundwater dynamics and for the recharge and to wilting point.

## 4.6 SATURATED ZONE

### 4.6.1 Geological model

Dynamic groundwater flow and potential heads are simulated by MIKE SHE. The modelling system requires a fully 3-dimensional geological model describing the extent, thicknesses and elevation of all major geological units. The geological model for the Paya Indah wetland catchment was developed based on (1)- a hydrogeological investigation which was carried out as a part of this research (Figure 4.17 and Appendix I) and (2)- past surveys conducted throughout the area by Bahaa-eldin et al. (2008), Minerals Geoscience Department of Malaysia (2002).

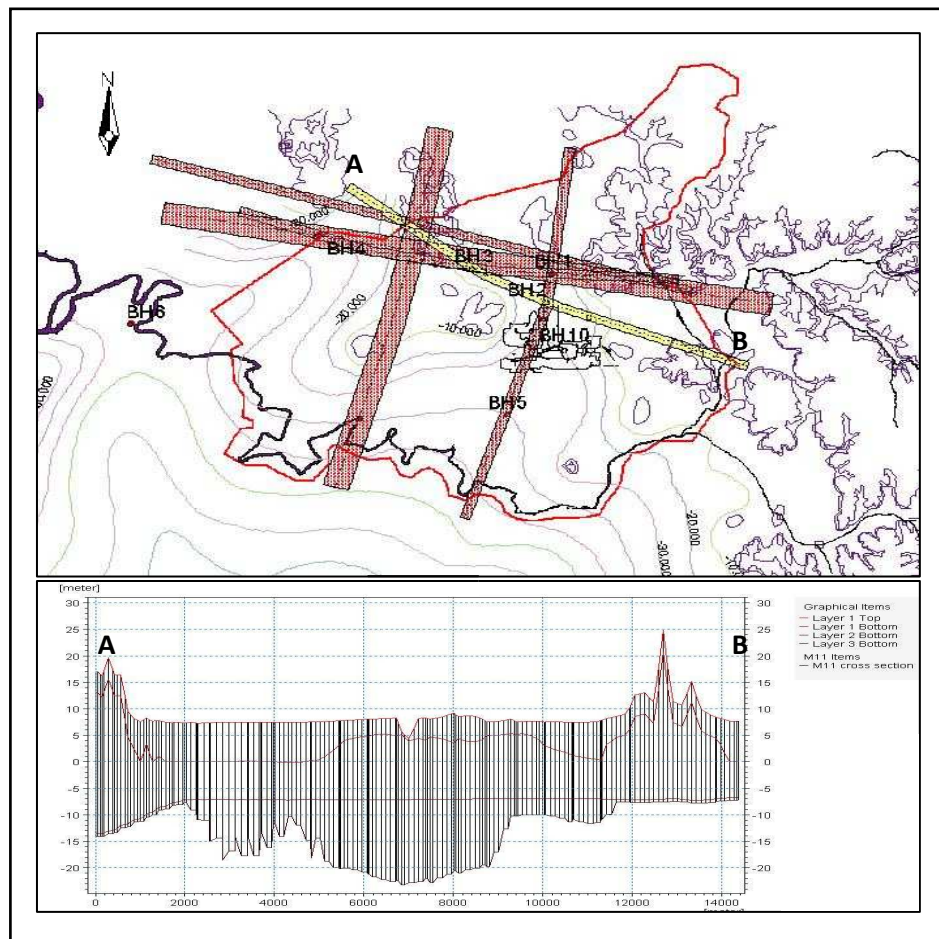


FIGURE 4.17

Presentation of a Geological Cross-section across the Modelled Area

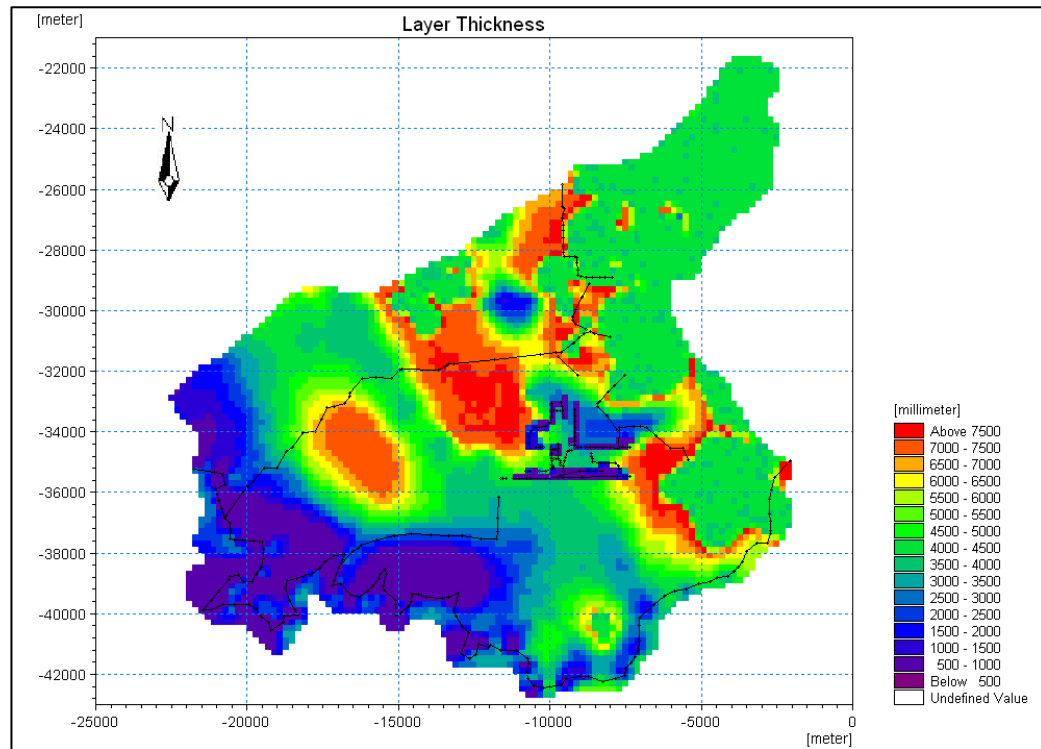
Accordingly the overall geology in the Cyberjaya area comprises the following lithological units:

- Alluvium of peat, clays and silts and unconsolidated deposits in the low-lying areas. The alluvium overlays metasedimentary rocks (the Kuala Lumpur Limestone and the Kenny Hill Formation)
- Sandstone interbedded with shale strata (belonging to the Kenny Hill formation) exposed along the eastern part of Cyberjaya and in small isolated “islands” in western area.

Limestone (belonging to the Kuala Lumpur Limestone formation) occurring in the north-western part of the area underlying alluvial sediments. A permeable aquifer is expected in an alluvium buried valley. This valley is probably of south-north direction possibly crossing the ex-tin mining lakes. The old mine lakes are situated directly into the alluvial aquifer sediments. Mining has disturbed the soils and the original geological settings are now overlaid with secondary mining deposits. The processed geological layers are presented in Figures 4.18 to 4.20. Accordingly the thickness variation of each geological layer can be described as follows:

- Layer 1 – Peat/peaty-clay, 5 - 8 m thick
- Layer 2 – Silty clay/sandy clay (aquitard), approximately 20 m thick
- Layer 3 – Silty sand/gravel (aquifer), approximately 30 m to 60 m thick (towards the Malacca Strait)

Extensive pumping tests had been conducted by previous researchers including Minerals Geoscience Department of Malaysia (2002) and Bahaa-eldin et al. (2008) in the Paya Indah area and Ampar Tenang village (in the proximity of Paya Indah area) respectively. However a new pumping test was conducted by this study in order to update the data (Appendix J).



**FIGURE 4.18**  
Thickness of the Geological Layer 1

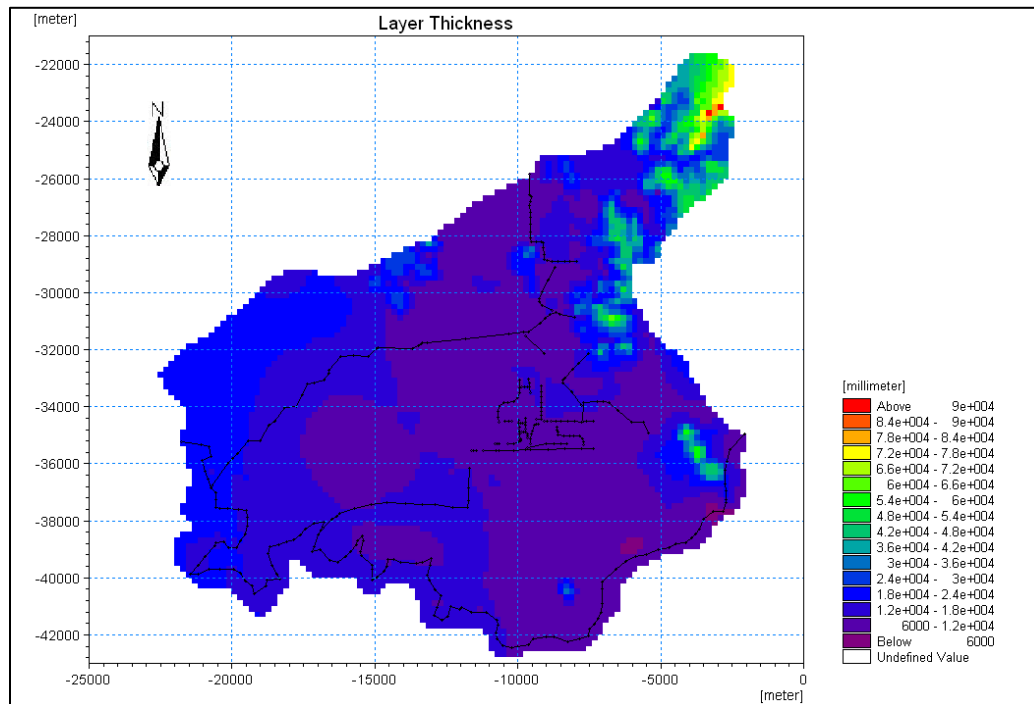


FIGURE 4.19  
Thickness of the Geological Layer 2

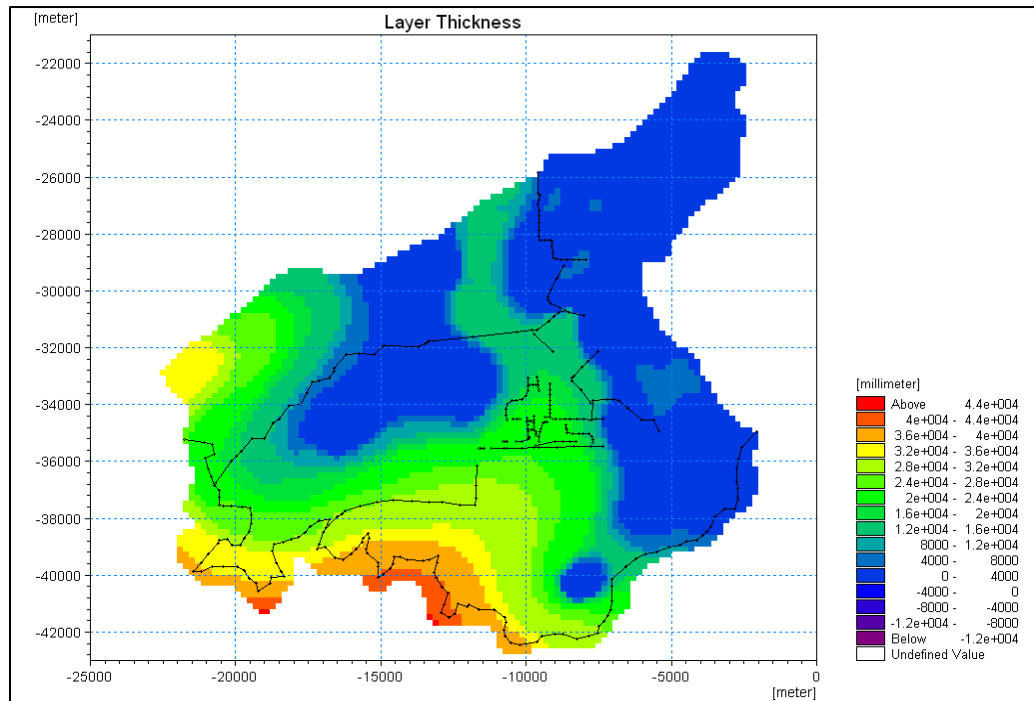


FIGURE 4.20  
Thickness of the Geological Layer 3



#### 4.6.2 Aquifers characteristics

The geological layers are assumed to account for the exchange with the river and channel network and to constitute the major source of groundwater in the model area.

Based on the pumping and field permeability tests that were carried out by the current study (Appendix J) and Minerals and Geoscience Department of Malaysia (2002) the hydraulic conductivity of the aquitard (Layer 2) is in order of  $9.95\text{E-}7$  to  $1.2\text{E-}8$  m/s. Thus, the Paya Indah lakes system is not in direct hydraulic contacts with the aquifer which in turn can indicate that the lakes do not recharge the aquifer. This conclusion also was supported by the fact that these lakes were filled up with mining material (clays/silts) and therefore appear almost impermeable (Minerals and Geoscience Department of Malaysia, 2002). Furthermore the large hydraulic gradients that are observed for the Paya Indah lakes system (different lake water levels) would not be naturally possible if the lakes were settled in highly permeable soils during periods with none or little inflow to Paya Indah. The transmissivity of the aquifer ranges between  $4.1\text{E-}3$  m<sup>2</sup>/s to  $3.3\text{E-}5$  m<sup>2</sup>/s (Table 4.4).

TABLE 4.4  
Characteristics of Shallow and Deep Aquifers at the Paya Indah Wetland Catchment

Aquifer properties	Clayey Peat	Silty Sand
Hydraulic conductivity $k$ (m/s)	0.0001 - 7.118e-005	1.0e-04 - 7.0e-05
Transmissivity $T$ (m <sup>2</sup> /h)	0.15	0.12
Storage coefficient $S_c$	0.001	4.5e-005
Leakage coefficient	0.0001	5e-007

### **4.6.3 Interactions between the surface and subsurface flow**

During wet season and storm events in particular the groundwater table rises normally closer or even above the ground surface as in peat swamp forest. Accordingly, the interaction between the surface water and groundwater is of great importance for this research to consider. The interaction between surface and sub-surface flow can be divided into three levels which include (i) exchange between overland water and the underlying soil (ii) unsaturated and saturated zones exchange flows and (iii) baseflow. The numerical model handles all the three situations.

### **4.6.4 Groundwater abstraction**

Withdrawal of groundwater is specified as a part of the input for the groundwater component. Groundwater withdrawal within the Paya Indah wetland catchment takes place at the properties of Megasteel Co. Ltd (Figure 4.21). It seems that after the study done by Minerals and Geosciences Department of Malaysia (2002) there is no regular monitoring for the groundwater withdrawal rate except one study sponsored by the Megasteel (Smart Survey Consultant, 2007). Accordingly for this study both values of groundwater abstraction measured by Minerals and Geosciences Department of Malaysia (2002) and the Smart Survey Consultant (2007) were applied to the PIW model.

Unlike JICA team (Minerals and Geosciences Department of Malaysia, 2002) who measured the totalized consumption at 23,300 m<sup>3</sup>/day, Megasteel Co. Ltd measured it at 15,551.65 m<sup>3</sup>/day and 12,079.6 m<sup>3</sup>/day during dry and wet seasons respectively (Smart

Survey Consultant, 2007). However, by applying the value of groundwater abstraction volume measured by the Megasteel Co. Ltd. we ended up with imbalance model.'

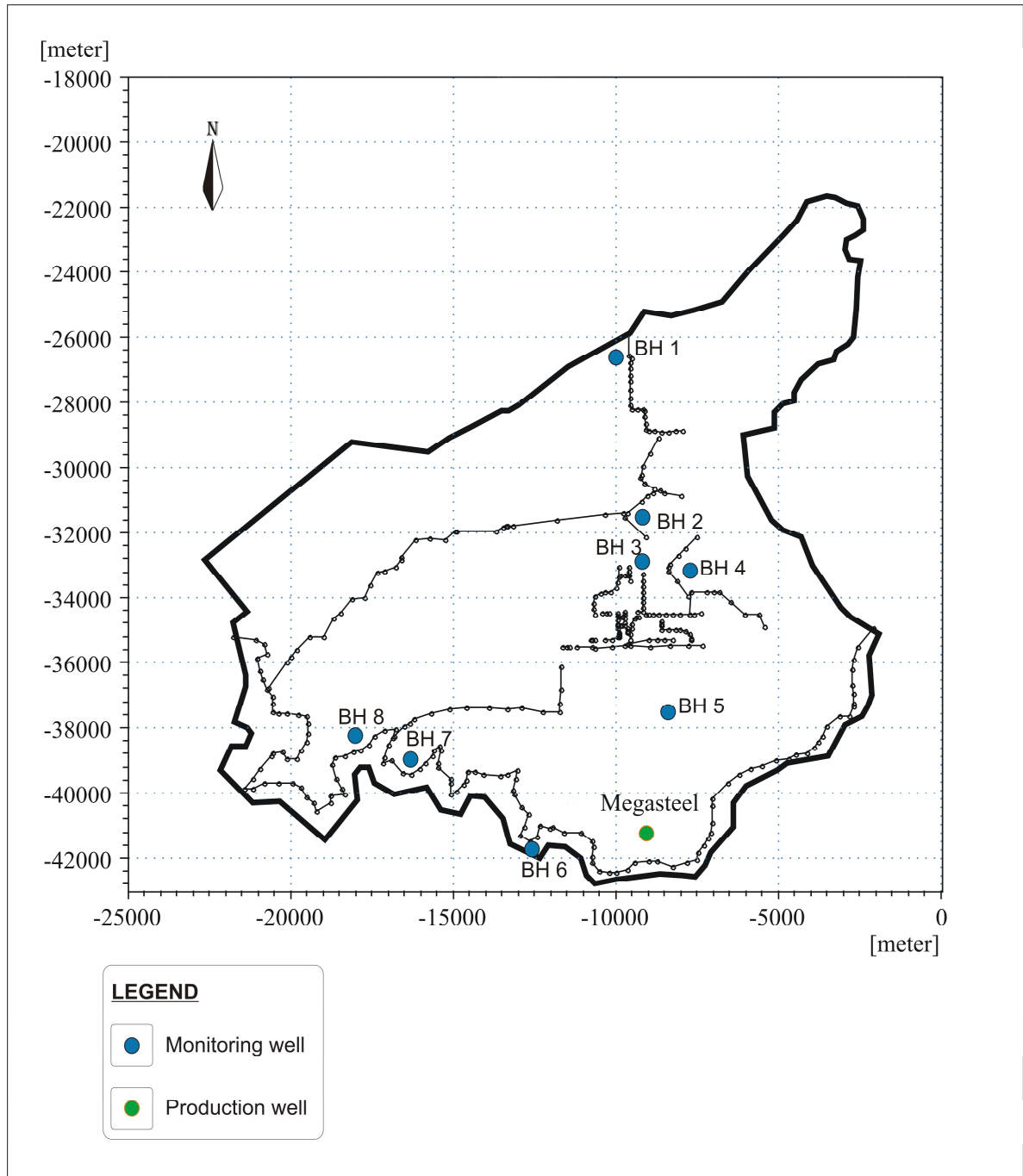


FIGURE 4.21  
Location of Monitoring and Production Wells within the Modelled Area

#### **4.7 SURFACE-WATER AND GROUNDWATER TIMESERIES DATA**

With exception to the lakes water level timeseries which were used in calibration, all the other timeseries data used for calibration and validation were measured using automatic loggers which installed purposely for this study. The loggers were adjusted to take reading in hourly biases. However due to vandalism issue (mainly unnecessary interference of some outsiders) six loggers were either smashed or lost. These included the loggers which were installed at North-Inlet-Canal (SWL1), Lotus-Outlet (SWL2) and the piezometers BH1, BH2, BH4 and BH8.

Historical data including surface water level, groundwater potential head were obtained from Malaysian Wetland Foundation and Minerals and Geoscience Department of Malaysia respectively. While as data of discharge rate of Langat River were obtained from Drainage and Irrigation Department of Malaysia.

#### **4.8 MODEL SET-UP**

The vertical flow in the unsaturated soil column and the water content profile is calculated solving the Richard's equation for gravity flow i.e. disregarding capillary effects. The unsaturated zone does not require specification of boundary conditions. The groundwater table of the shallow aquifer of Peat constitutes the lower boundary for the unsaturated zone within each of the soil columns. The upper boundary may act as a flux boundary when the soil has sufficient infiltration capacity. When the infiltration capacity is exceeded, a head boundary is applied depending on overland water depth. When groundwater tables rises above

the ground surface the unsaturated zone flow calculations are replaced by the groundwater component.

#### **4.8.1 Boundary conditions**

The model boundary was defined based on the considerations and understanding of the hydrological and hydrogeological systems of the modelled catchment.

Letter notations refer to notations used in Figure 4.22. Along the Northeastern boundary (A) the model boundary follows the topographic water divide between Langat and Klang River Basins. The alluvial system is not found in this out-crop area and it was assumed that there are no sub-surface inflows to the model area. This assumption was kept along the entire eastern boundary (A) until it meets the Langat River (G). Most of the net-rainfall in the north-eastern corner of the model would drain south-west and end up in the drainage channels (B) that diverts water further west or north to Klang river basin. The drainage channels (B) diverts the water further west through culverts in the North-South Expressway Central Link (NSECL) (C) and continues to the west and southwest to (C1) from where it ends up in Langat River. Part of the runoff from the uppermost North-eastern corner of the model might be caught by drainage channels along the new Putrajaya-Link (A2) from where it drains north into the Klang River Basin. The export of water to the Klang River basin was simulated by including the drainage channels along the Putrajaya-Link in the hydraulic model. These channels would then receive subsurface inflows and drainflow (interflow and urban runoff) from the upstream area. The model area follows the drainage channel along the Putrajaya-Link (A1) until it meets the new North South Expressway Central Link (NSECL). Drainage channel along NSECL diverts water further north to the Klang River

Basin. Along this boundary the alluvium is present and subsurface flows might cross the boundary at (A1). For the upper layer (peat and peaty clay) it will, however, be assumed that the drainage channel intercepts all subsurface flows. Hence, for the upper layer a zero-flux boundary will be adopted in the groundwater model. For the boundary of the deeper alluvium (the aquifer) there might be subsurface flows across the boundary and open boundary, thus, a prescribed head boundary was adopted at (A1).



FIGURE 4.22

Boundary Conditions for the Study Area. A: Water divide between Langat and Klang River Basins; A1: Drainage channel along NSECL; A2: Drainage channels along the Putrajaya-Link; B: Drainage channels flows towards Klang River Basin; C: Culverts of NSECL; C1 :N & NW drainage along NSECL; D: Culverts of NSECL diverts water towards PI Lake System; E: Louts outlet; F: Peat Basin; G: Langat River; G1: Oil palm plantations artificial drainage system; H: Water drains outside the catchment; K: Primary drainage channels in the oil palm plantation

Further to the west (F) the model area crosses the peat basin and a hydrologically well defined boundary was difficult to establish. Peat is highly permeable and a zero-flux boundary was not necessarily a justified approximation. It was found, however, reasonable to assume that horizontal flows across (F) in the peat layer would be small unless the peat might be disturbed by anthropogenic (drainage, pumping etc) or natural stresses (spatial variations in rainfall and recharge). There were no apparent anthropogenic or natural stresses had been noticed at that part of the catchment. Furthermore the boundary (F) is located across a narrow section in the peat swamp. It was therefore considered a reasonable approximation to adopt a no-flux boundary for the peat layer. Finally (F) is located in good distance from the key interest area. Similar to (A1) there may be deeper subsurface flows where an open (prescribed head) boundary must be employed.

Further to the north-west (K) the model boundary follows one of the primary drainage channels in the oil palm plantation. It was assumed that the drainage channel would intercept horizontal subsurface flows in the upper layer and thus a zero-flux boundary would be employed in the upper layer. The underlying aquifer might be unaffected by the drainage channel and an open boundary would be needed.

The southern model boundary follows Langat River. Similar to above it was assumed that Langat River intercepts horizontal subsurface flows in the upper peat layer and the upper layer was therefore adopt a zero-flux boundary for the upper layer. The Langat River itself was included in the hydraulic modelling component and would thus control simulated groundwater levels in the upper layer. If there was no hydraulic contact between the river and the underlying aquifer an open boundary would be adopted for the aquifer.

Most of the southern part of the model area (G1) is oil palm plantations and is artificially (moderately) drained. In the model it was assumed that the oil palm plantation drains south towards Langat River. A conceptual representation of the drains was adopted where a drainage level was specified within the oil palm plantation. If the simulated groundwater level exceeded the drainage level drainflow would be produced and routed to Langat River. The drainage level should reflect the water level in the drainage channels which typically is in the order of 0.5 meter below ground surface.

On the eastern side of the NSECL a small portion of the Cyberjaya area drains east (H) out of the model area and ends up in Langat River. The channel (H) was represented in the model to account for this water export.

For the geological model, the following boundaries were assigned:

1. Layer 1 (Peat): Zero-flux was assigned along the eastern and northern boundary above the eastern reach of Langat River. A zero-flux also was assigned along the entire southern boundary of the catchment (Langat River).
2. Layer 2: Zero flux boundaries were adopted along the entire model boundary, implying that there is no groundwater flow across the model boundary.
3. For layer 3 (aquifer): a fixed head boundary was adopted.



#### 4.8.2 Surface water flow system

The surface water flows and water levels are modelled with the 1-Dimensional MIKE11 model in combination with the 2-Dimensional overland flow model in MIKE SHE. The channel model (MIKE11) will receive lateral inflows composed by baseflow (groundwater flow), interflow/drainflow (from subsurface drains/ditches) and from overland flow. The channel model then calculated flows and water levels in channels and lakes. Based on hydraulic gradients (surface water/groundwater) channels and lakes may both drain or recharge the aquifer (baseflow component).

Required input data for the MIKE11 model consists surface roughness coefficient or Manning's number 'M', the reciprocal to the Manning's 'n', for the different land covers. Manning's empirical formula is used for the mean velocity of gravity-driven, uniform, fully developed turbulent flows in rough open channels. The formula is customarily used to determine the capacity of natural streams and flood plains, and to design artificial channels. Manning's Formula is usually written in the dimensionally inconsistent form as in equation 4.8 (Gioia and Bombardelli, 2002):

$$v = \frac{1.49}{n} R^{2/3} S^{1/2} \quad (4.8)$$

where

$V$ : is the mean flow velocity (ft/s)

$n$ : is Manning's n (roughness coefficient)

$R$ : is the hydraulic radius ( $a/P$ ) where  $P$  is the wetted perimeter (ft)

$S$ : is the channel bed slope as a fraction

1.49: is a unit conversion factor. However 1.0 will be used instead if SI (metric) units (International System of Units) are used.

The values of Manning's  $n$  for the present study were taken from the literature (Chow, 1959) and shown in Table 4.5.

TABLE 4.5  
Roughness Coefficient (Manning's coefficient) used for the Channels in the study area

Type of Channel	Manning's Coefficient Values		
	Range	$n$	$M^*$
Channels not maintained, weeds and brush uncut: dense weeds, high as flow depth	Minimum	0.5	05.0
	Normal	0.80	08.0
	Maximum	1.00	10.0

\* The reciprocal of Manning's  $n$   
Source: Chow (1959)

Operation schedules are among the required input data for any water balance accurate calculation. Although there were some operations at the weir at Lotus Outlet (Figure 4.7) but according to the Paya Indah local authorities there are no measurements have been recorded. The surface water model (MIKE11) includes the channels shown in Figure 4.22.

Higher order drainage channels were not included in the branch network. Instead these were simulated in a more simplified and conceptual manner using what so-called “drainage option” in MIKE SHE. The drainage option allows for specification of a drainage level, a time-constant for linear reservoir routing of drainflow and for specification of drainflow recipient. The latter was typically a river or a lake but water may also get exported from the model area if feasible. The oil palm plantations in the southern part of the model area adopted this drainage option. In practice the drainage option maintains the groundwater level below the specified drainage level and routes groundwater to the specified recipient. In this case the recipient was Langat River and channels E and G (Figure 4.22) in the hydraulic model, which runs through the oil palm plantations.

As discussed in Chapter 4.8.1, all upstream ends the model adopts a zero-flow boundary implying that no water enters the rivers at the upstream end. Flow in the branches is produced entirely within the basin and comes in as lateral inflows consisting of overland flow, drainflow (interflow) and baseflow (groundwater flow).

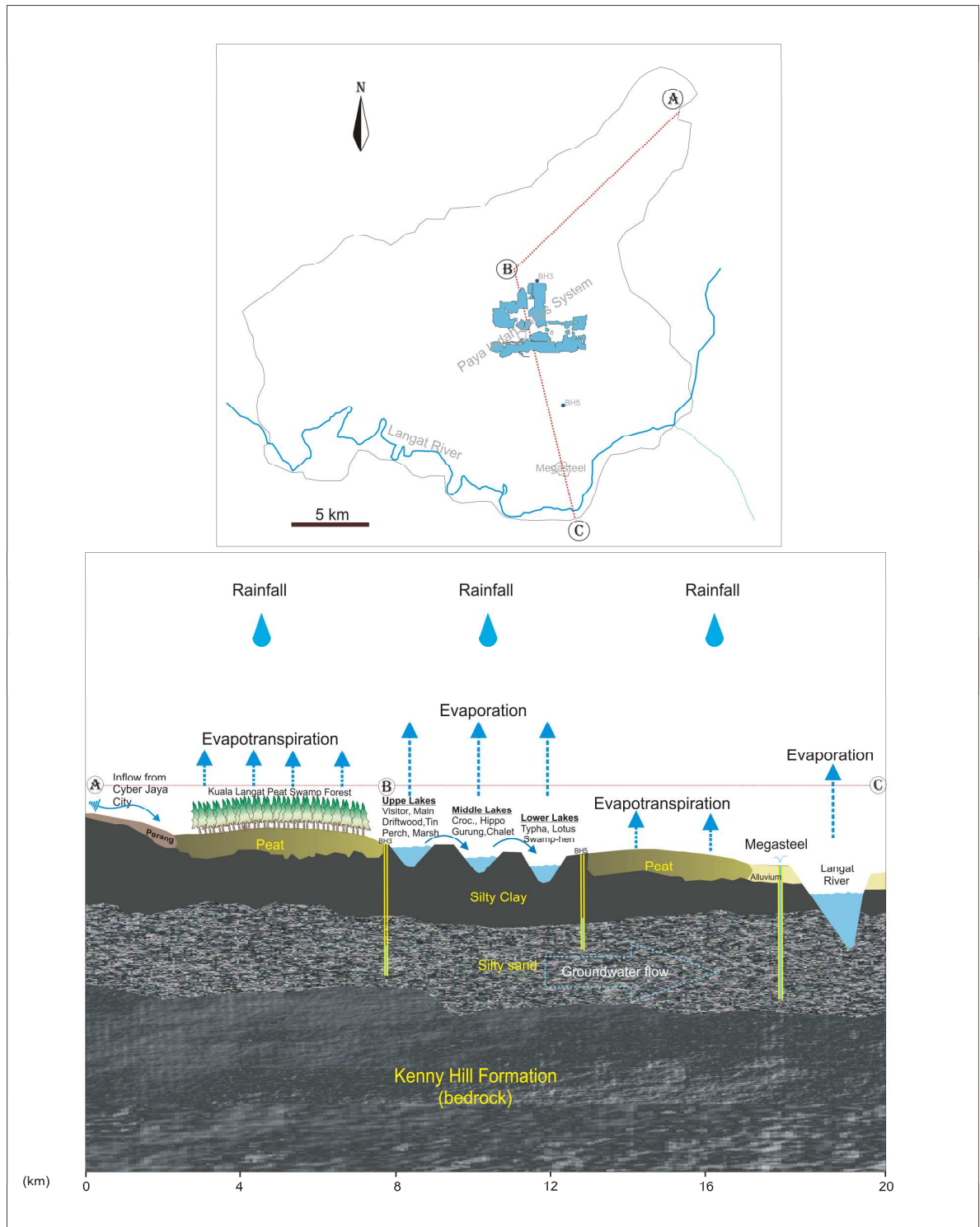
## **4.9 CONCEPTUAL MODEL**

The water flows in the lake system mainly from rain and a considerable contribution of flow from the adjacent uplands including Cyberjaya City and Kuala Langat peat swamp forest. The groundwater model includes 3 layers. The top layer (layer 1) contains the peat swamp and less permeable alluvial sediments. The second layer (layer 2) is the aquitard consisting of about 20 m silty clay which varies in the thickness due to undulation of the bedrock. The third layer (layer 3) is the aquifer of sandy and gravelly sediments. For layer 1 and layer 2 zero flux boundaries have been adopted along the entire model boundary, im-

plying that there is no groundwater flow across the model boundary. For layer 3 a constant head boundary has been adopted from the study conducted by Minerals and Geoscience Department of Malaysia (2002). Figure 4.23 illustrates the conceptual model of the Paya Indah wetland. At some locations (higher elevation areas) the bedrock rises to the ground surface and thus intersects the alluvial sediments. This feature is incorporated automatically by MIKE SHE's pre-processor by assignments of the hydraulic properties of the bedrock in all layers (cells) that are intersected by the bedrock.

For the hydraulic model water inflow were specified at all free upstream ends and water levels at free downstream ends. Flow in the branches is produced entirely within the catchment and comes in as lateral inflows consisting of overland flow, drainflow (interflow) and baseflow (groundwater flow). The only free downstream ends are at Langat rivers outlet in the Strait of Malacca where a tidal water level boundary should be adopted, however this part of the Langat River is out of the modelled catchment boundary.

Groundwater inflows that enter the hydraulic model (baseflow) are calculated, using Darcy's equation, as a function of the head gradient between the canal water level and the adjacent groundwater level and a hydraulic resistance (leakage coefficient) which controls the surface water-groundwater exchange rates. In the Paya Indah wetland model the leakage coefficient was calculated by the MIKE SHE pre-processor depending on the hydraulic input data of geological settings that surrounds the canal. Thus if the river runs through highly permeable soils, such as peat, there would be a small hydraulic resistance (large leakage coefficient) while clayey sediments would create a large resistance (small leakage coefficient).



**FIGURE 4.23**  
Conceptual Model of the Paya Indah Wetland Catchment

The Paya Indah Lakes are modelled as normal branches in MIKE11. The lakes do however appear with a spatial distribution on the ground surface and thus receives direct rainfall as well as depletion by open water evaporation. Considering the Cyberjaya developments, drainage schemes have been implemented that do not always follow the natural slopes of the terrain. In such areas the overland flow model has basically been disabled and the surface runoff is described by a conceptual linear reservoir routing model that routes ponded water to a prescribed recipient in the hydraulic model (Cyberjaya canal). In addition to these fixed urban drainage plans, the topographic information in the low-lying areas is not sufficiently detailed for a proper overland flow description, where surface water, groundwater and climate interactions are substantial.

The model could produce observed groundwater and surface water dynamics created due to the change in the rate of inflow at SWL1, groundwater abstraction, and elevated rate of daily evapotranspiration. Thus, it was justified to use the model to predict relative impacts that might occur in water level of the Paya Indah lakes systems and the deep aquifer.

#### **4.10 MODEL DOMAIN AND DISCRETIZATION**

The model uses Cassini coordinates of Selangor State of Malaysia in metric units and covers an area of 242.21 km<sup>2</sup> which was chosen based on the considerations outlined in the section 4.7 (Figure 4.24). While in the numerical model the model area is discretized in a mesh consisting of 6500 cells of 200x200 m as illustrated in Figure 4.25.

For the groundwater model, the total number of computational cells then added up to about 19500 cells. Then the hydraulic model comes on top of that, the unsaturated zone model and the overland flow model. The groundwater model is however the computationally most demanding simulation module. On a 1 GHz laptop 1 year of simulation takes around 10 minutes. The 200x200 m discretization is relatively coarse but suitable for calculating the overall water balance and impacts from large scale development (Va'zquez and Feyen 2007; Zhiqiang et al., 2008) such as in the Cyberjaya. However, the model can easily be refined or zoom models can be created which is considered a feasible representation.

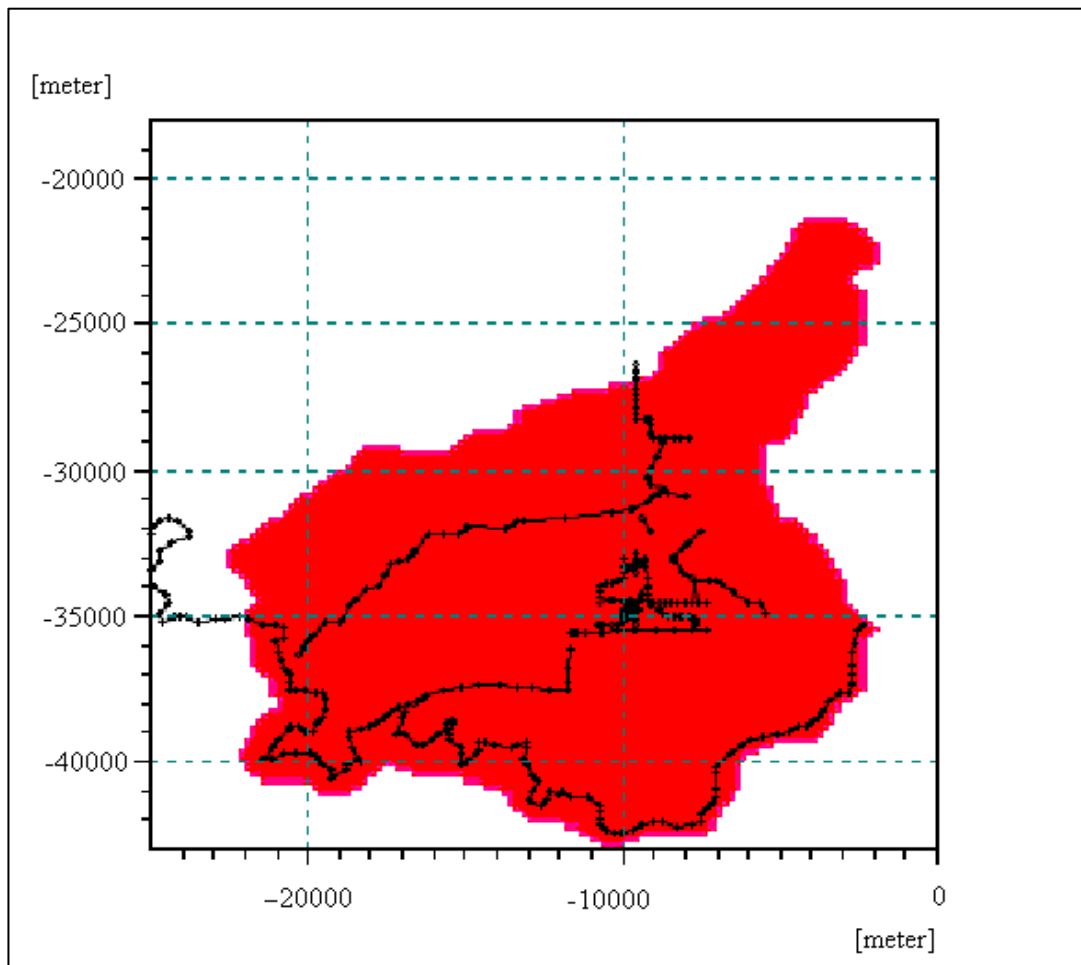


FIGURE 4.24  
Model Domain and Grid

#### 4.11 MODEL DEVELOPMENT

A total of five years and four months of data were set up for model calibration, while as one year's run was considered for model validation. Built-in statistical tools were used to analyze the results in order to evaluate the model performance for both calibration and validation processes.

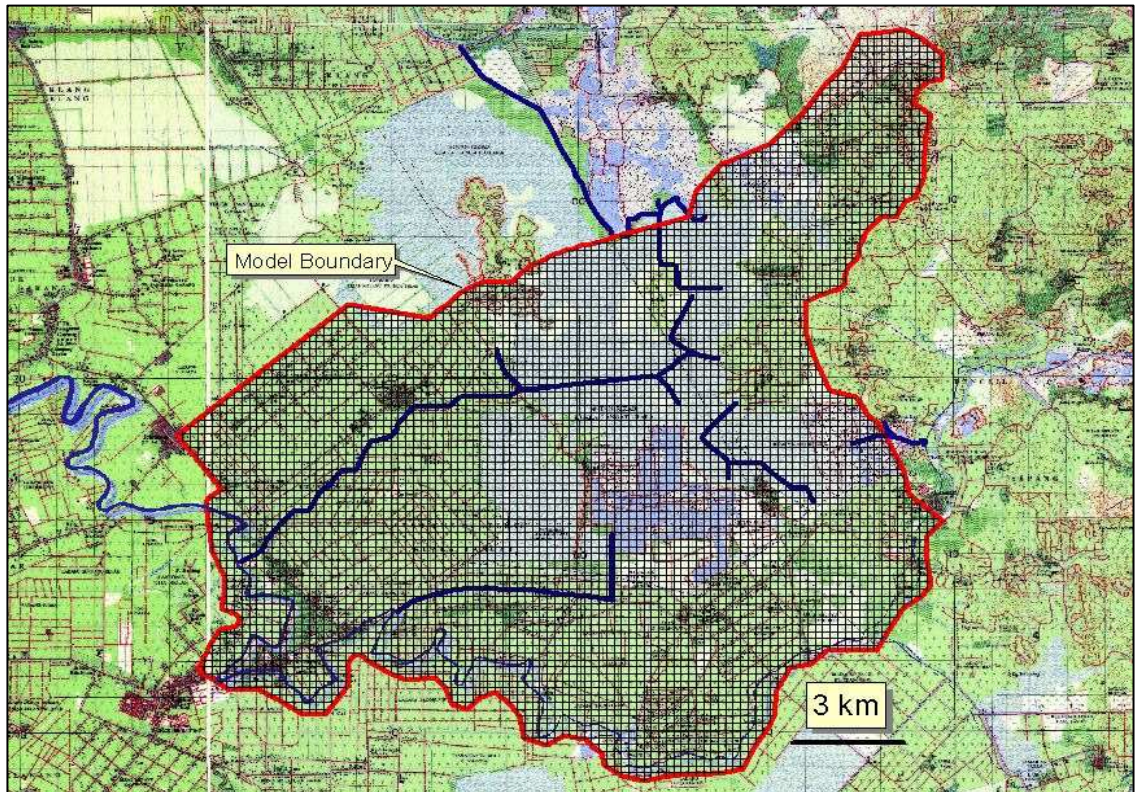


FIGURE 4.25  
Mesh Discretization for the Study Area



#### 4.11.1 Simulation time step

Each of the main hydrologic components in MIKE SHE runs with independent time steps. Although, the time step is automatically controlled, whenever possible, MIKE SHE will run with the maximum allowed time steps (Danish Hydraulic Institute, 2007). The component time steps are independent, but they must meet to exchange flows, which leads to some restrictions on the specification of the maximum allowed time steps. These restrictions include:

- If MIKE 11 is running with a constant time step, then the Max allowed Overland (OL) time step must be a multiple of the MIKE 11 constant time step. If MIKE 11 is running with a variable time step, then the actual OL time step will be truncated to match up with the nearest MIKE 11 time step.
- The Max allowed UZ time step must be an even multiple of the Max allowed OL time step.
- The Max allowed SZ time step must be an even multiple of the Max allowed UZ time step.

Thus, the overland time step is always less than or equal to the UZ time step and the UZ time step is always less than or equal to the SZ time step. Accordingly, the time steps used in the model for efficient simulation are: initial unsaturated zone time step (2.0 hours); maximum unsaturated zone time step (6.0 hours); maximum saturated zone time step (12.0 hours); minimum overland flow time step (0.083 hours); maximum overland flow time step (6.0 hours). The time steps are critical for minimizing overland water balance error which should be less than 1.0 % of the total precipitation.

#### **4.11.2 Model Calibration**

Model parameters were set within an appropriate range to adequately represent the system being modelled during calibration which is an iterative process covered the period from July 1<sup>st</sup>, 1999 to October 31<sup>st</sup>, 2004. During this process, each model parameter is varied following a trial and error procedure, with all other parameters being constant. Formal sensitivity analysis was performed during this study. It was found that during the calibration process that evapotranspiration (ET) and the groundwater abstraction were sensitive model outputs. However, given the inability to fully characterize all hydrological processes and the possible difference in scale between the measurement and the model grid square, slight calibration is generally required. Consequently, the model was calibrated by adjusting the Manning's M, infiltration rates and vertical and horizontal hydraulic conductivity for the three geological layers.

#### **4.11.3 Model Validation**

Using parameters fine-tuned in the calibration process, the model was validated with the data covering the period from August 2007 to August 2008. This period considered all the critical landuse changes occurred within the catchment.

#### **4.11.4 Model Performance**

In addition to qualitative assessment with graphical displays, the model simulation results were evaluated quantitatively using statistical measures. Statistical parameters such as regression coefficients, mean error (ME), mean absolute error (MAE), root mean square error (RMSE), standard deviation of residuals ( $STD_{res}$ ) and coefficient of correlation (R) were

used. Furthermore, Pearson type-I ( $R^2$ ) distribution index and model coefficient of efficiency (CE) were used to assess representativeness efficiency of the model.

The mean error (ME) calculates confidence intervals for the mean between the observed and simulated data (Equation 4.9); while as the mean absolute error (MAE) measures how close simulations are to the eventual outputs (Equation 4.10). The root mean square error (RMSE) measures the difference between simulated and observed values and it is sensitive to the extreme values and deals with both systematic and random errors (Equation 4.11).

As large biases may exist due to scaling problems, i.e. the dissimilarity between the measurement scale (at a point) and the modelling scale (on a grid) and the associated heterogeneity within the model grid (Khu et al., 2008), the standard deviations of residuals ( $STD_{res}$ ) was used to evaluate simulation accuracy at location  $i$  where  $n$  observations exist, thus suggests whether the model over- or under-simulated the values (Equation 4.12).

The linear correlation coefficient (R) is a measure of accuracy or the strength and direction to which the observed and simulated values agree (Equation 4.13). The goodness-of-fit between observed and simulated daily stream flow in Langat River and the average monthly flow at Outlet (SWL2) were measured by the Pearson type-I ( $R^2$ ) distribution index function and model efficiency coefficient (CE); these were originally published by Pearson (1895) and Nash and Sutcliffe (1970) respectively. Equations 4.14 and 4.15 represent  $R^2$  and CE respectively. A value of 1 (optimal) represents a perfect model, while a value of zero (0) shows a prediction no better than using the mean of the data.

$$ME = \frac{1}{n} \sum_{i=1}^n (O_i - S_i) \quad (4.9)$$

$$MAE = \frac{1}{n} \sum_{i=1}^n |O_i - S_i| \quad (4.10)$$

$$RMSE = \frac{\left[ \sum_{i=1}^n (O_i - S_i)^2 \right]^{\frac{1}{2}}}{n-1} \quad (4.11)$$

$$STDres = \sqrt{\frac{\sum_t [(O_{i,t} - S_{i,t}) - ME]^2}{n}} \quad (4.12)$$

$$R = \frac{n \sum xy - (\sum x)(\sum y)}{\sqrt{n \sum x^2 - (\sum x)^2} \times \sqrt{n \sum y^2 - (\sum y)^2}} \quad (4.13)$$

$$R^2 = \left( \frac{\sum_{i=1}^n (Q_i - \bar{Q})(q_i - \bar{q})}{\sqrt{\sum_{i=1}^n (Q_i - \bar{Q})^2} \sqrt{\sum_{i=1}^n (q_i - \bar{q})^2}} \right)^2 \quad (4.14)$$

$$CE = 1 - \frac{\sum_{i=1}^n (Q_i - q_i)^2}{\sum_{i=1}^n (Q_i - \bar{Q})^2} \quad (4.15)$$

where,

$O_i$  is the observed water level

$S_i$  is the simulated water level

$Q_i$  is the observed flow

$q_i$  is the simulated flow

$\overline{Q}$  is the mean observed flow

$\overline{q}$  is the mean simulated flow

$n$  total number of observations

$i$  is location of observation

$t$  is time of observation

Soils data on the other hand, were subjected to descriptive statistical analysis in order to define their distribution significance throughout the study area. The statistical analyses were performed using the SPSS FOR WINDOWS statistical software package, Release 11.50 (6 September 2002). Simple correlation analysis was used to examine the relationship between the analyzed soils. However, wherever applicable, all the processed data including soil were discussed in terms of averages and 95 % confidence intervals. Statistical differences between the means were compared using least significant differences at probability  $P \leq 0.05$  (significant) and  $P \leq 0.01$  (very significant).